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Repurposing Options for Coal Mines in India

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Abbreviations

Abbreviation	Full Form
ALARP	As low as reasonably practical
AML	Abandoned mining land
BESS	Battery energy storage system
CAES	Compressed air energy storage
CO_2	Carbon dioxide
CSP	Concentrated solar power
CIL	Coal India Limited
EES	Electrical energy storage
GBI	Generation based incentive
GBR	Geotechnical baseline report
GES	Gravity energy storage
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH
GW	Gigawatt
Hr	Hour
HTF	Heat transfer fluid
HWT	Hydraulic Wind Turbines
IREDA	Indian renewable energy & development agency
Km	Kilometer
KW	Kilowatt
KWh	Kilowatt-hour
LKL	Lakh Kilo Liter
MT	Metric Tonne
MNRE	Ministry of new and renewable energy
MW	Megawatt
MWh	Megawatt-hour
PBI	Procurement based incentive
PLI	Production linked incentive
PV	Photo voltaic
RDD&D	Research design development and demonstration
SPPD	Solar power park developer
TIES	The international ecotourism society

Abstract

Mining plays a crucial role in human civilization, contributing essential minerals for various products, from everyday items to sophisticated technologies. Despite its historical significance, the environmental impact of mining remains a challenge, and the temporary nature of mines often leads to the decline in social standards of nearby communities once operations cease. As the world is shifting towards sustainability it has become important to address the environmental and social challenges that are being faced due to mining activities.

This project centers on exploring the repurposing potential of closed, abandoned, or discontinued mines, with a particular emphasis on coal mines in India. The objective is to leverage existing land and infrastructure of a mine. The report delves into the concept of repurposing of mines, citing examples from various countries where mines have been transformed into eco-commercial zones, energy storage zones, clean energy zones. Additionally, it provides a comprehensive list of coal mines in India, including those that have been abandoned.

With the increasing adoption of renewable energy sources and the ambitious targets set by the Government of India aiming towards achieving net zero emission by 2070, the need for efficient energy storage solutions becomes paramount to address fluctuations in power generation and this report emphasizes on battery energy storage solutions that can be established at a mine site such as pumped storage hydropower, pumped underground storage hydropower, gravity storage, compressed air storage, hydrogen storage, thermal energy storage which can be used in combination to solar PV, wind energy and geothermal energy. Apart from these several other repurposing options have also been covered in this report.

In this report PwC has covered best practices, working principle, conditions determining the suitability, symbiosis with other repurposing options, environmental impact, employment effects, economic feasibility, pros and cons and suitability for India for each of the nineteen identified repurposing options. In addition to it some other repurposing options that can be established at abandoned mine sites such as data storage, leisure facility, infrastructure facility, and nuclear waste disposal facility have been covered in this report by sighting some global examples of the same.

Some of the key findings of this report are as follows:

- Repurposing serves better to the society and is more environmentally friendly than just reclaiming the land.
- As a forerunner, CIL is planning to conduct feasibility studies for 20 coal mines for assessing the potential of repurposing the mine with PSH or PUSH.
- While establishing PSH or PUSH, locations with low pH value of water should be avoided, as acid goaf water could corrode the plant components, and release metal ions, or heavy metals, thus damaging the underground structures and polluting the surrounding water bodies.
- The minimum head (hydraulic head) required for a viable pumped storage hydropower project typically ranges from 100 meters (approximately 328 feet) to 300 meters

(approximately 984 feet), although there are variations based on specific project conditions and objectives.

- Projects with less than six hours energy storage are generally not considered for battery energy storage on the basis that the minimum energy storage capacity requirement is likely to be six hours.
- In PSH/PUSH, Repurposing the existing abandoned coal mines as an upper or lower reservoir, or both, will reduce the capital cost of the project as it would have been in developing a new project with unfavorable topography.
- Repurposing of underground mines possesses significant geotechnical challenge of rock stability, and accessibility.
- Wind energy generation option can be easily adopted with other options as the land area utilization is near to about 5% of the total project area.
- Presence of power transmission infrastructure makes repurposing of mine sites much more lucrative.
- Amongst the nine mining states Jharkhand has the greatest number of coal mines which itself suggests that Jharkhand can be the best place to start with repurposing of coal mines in India.
- It was observed that most of the proved reserves of coal present in the Indian coal fields are lying within the range of (0-300) meters in India and such type of mines are most prominent in India.

In the later sections of this report, a comprehensive repurposing matrix has been meticulously crafted. This matrix outlines specific conditions that must be scrutinized to ascertain the suitability of each repurposing option. Additionally, a chart that illustrates the symbiotic relationships between various repurposing alternatives was added. These tools serve as critical resources for decision-makers, offering a systematic approach to assess and understand the nuances of each repurposing option.

Furthermore, this study encompasses a comprehensive mapping of coal mines across various mining states in India. To enhance practical utility, we have classified these coal mines into five distinct categories based on mining method, area, depth, and gassiness. This categorization serves as a valuable decision-making tool. Each category is meticulously matched with applicable repurposing options, providing a clear guide for individuals assessing a mine site. This strategic alignment ensures that stakeholders can make informed decisions regarding the most suitable repurposing strategies based on the unique characteristics of each coal mine.

The "Way Forward" section of this report strategically outlines the roles assigned to key stakeholders. Government entities, financiers, mining players, and academic institutions each will play pivotal roles in steering the repurposing endeavors of abandoned, closed, or discontinued mines.

Project Background

Ministry of Power (MoP) had released its guidelines to promote development of pump storage projects by utilizing exhausted mines in India which says that "The discarded mines including coal mines in different parts of the country could be used as Hydro Storage and thereby become natural enablers for the development of Hydro Pumped Storage Projects (PSP). Efforts would be made to identify and develop exhausted mines/coal mines as prospective PSP sites in consultation with the Ministry of Coal, Ministry of Mines."[1]

In regard to the above guideline, GIZ intends to conduct a study about the prospective repurposing options for exhausted/abandoned coal mines in India for which it has appointed PwCPL to provide the said services and conduct a detailed study to identify exhausted/abandoned coal mines as prospective sites for repurposing. This study pushes the repurposing scenario one step further by identifying 19 potential repurposing options for which a study will be conducted covering the following broad areas for each identified repurposing option.

- Introduction to the identified option
- Global best practices with examples
- Working principles of technology
- Conditions for suitability of technology
- Potential for symbiosis with other repurposing options
- Environmental impact and GHG reduction potential
- Effects on employment
- Economic feasibility analysis
- Pros and cons of the repurposing options
- Suitability for India

The list of repurposing options identified by GIZ that has to be studied for the purpose of this project goes as follows:

1. Pumped storage hydropower
2. Pumped underground storage hydropower
3. Compressed air storage
4. Hydrogen storage
5. Thermal energy storage
6. Gravity storage
7. CO2 storage
8. Wind energy on mining land
9. PV on mining land
10. Floating solar
11. Geothermal energy

12. Recreational parks
13. Ecotourism
14. Memorial / Museum
15. Waste disposal - bioreactor landfill
16. Water storage & flood protection
17. Wildlife habitat
18. Pisciculture
19. Horticulture

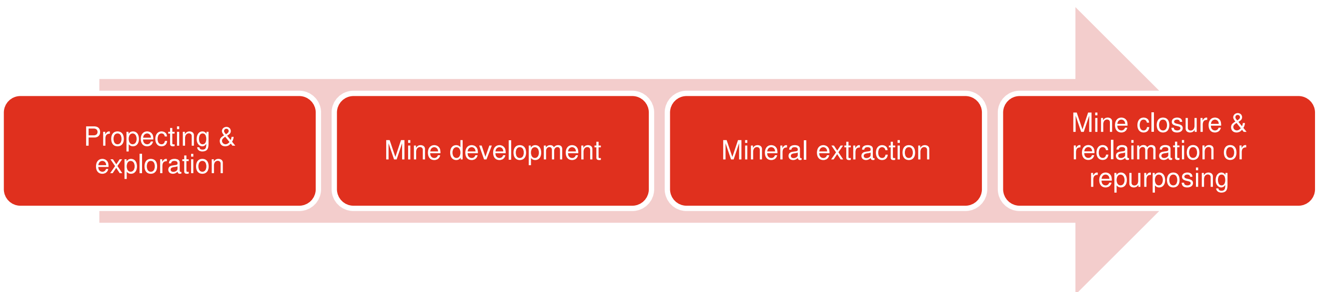
1. Introduction to Repurposing of Coal Mines

In general terms repurposing is the use of something other than its original use for which it was intended in the first place. Repurposing is generally adopted in the case where the original use becomes undesired or less useful in comparison to its usefulness after repurposing. Repurposing can be achieved by modifying or using an item or infrastructure in a new way. It can be said that repurposing is a new way of recycling things that cannot be recycled. If done properly it can lead to money saving and generate additional revenue streams.

A mine site has a lifetime ranging from few years to several decades. Once the mine is dead, activities such as landfilling, plantation, afforestation and harvesting take place but the former fertility becomes a statement of doubt. Reclamation processes are commenced as instructed by respective regulatory bodies. In reclamation process, after mining finishes or the mine is closed with no future scope of mining, the mine area must undergo reclamation to minimize environmental damage. This step in the mining process is critical to ensuring the sustainability of the land for future use. First, waste dumps are contoured to flatten them out and stabilize them, covered with soil, vegetation is planted, and the area is fenced to prevent livestock from eating the newly planted vegetation. The ownership of the land and reclamation process responsibility lies with the mine owner only.

Reclamation neither adds to the social status of the people living nearby nor does it create an avenue of revenue generation. If these areas are converted into socioeconomic zones, it'll not only help in enhancing the living standard of the people present in the nearby areas post the closure of a mine but will also generate sustainable revenue stream for them as well. For example, one such area is the Sudbury Neutrino observatory, which was built in INCO's (former name of Vale's) Creighton Mine near Sudbury, Ontario. While the other is Gotland Ring, Sweden, a world-class car racing track situated in an old limestone quarry. The Vale's Creighton Mine was owned by Vale Canada, and now SNOLAB is a science facility that is located deep underground, and its science program focuses on astro particle physics, specifically neutrino and dark matter studies, as the unique location is well-suited for biology and geology experiments while inspiring and educating future scientists[2]. Gotland Ring is the world's longest modern standard race and test circuit, that provide Grand Prix Coaching, Race Taxi, Trackdays, Seasoned Card and Tailored Corporate event services[3]. Such advancement contributes to the development of the mining area which was heavily dependent on the mining activities that used to take place earlier.

Figure 1: Mine Life Cycle



Source: PwC Analysis

1.1. Post Mine Life Scenario

Mines can be closed/abandoned/discontinued due to depletion of reserve, spontaneous heating, safety reasons, inundation, adverse techno-economics, financial losses, adverse geo-mining conditions, surface constraints, local issues, infeasible mining conditions at present, environmental impacts, etc.

There are three aspects covering the closed, abandoned, and discontinued mines which is illustrated in the diagram given below.

Figure 2: 3Rs for closed, abandoned or discontinued mines.

Source: PwC Analysis

Re-operationalization: Mines that are currently closed, abandoned, or discontinued due to infeasibility of the mining operation considering the impacts of global market conditions and variation in commodity prices but can be economically viable and operational in future with advancement in technology and mining methods.

Reclamation and Rehabilitation: After mining finishes or the mine is closed with no future scope of mining, the mine area must undergo reclamation to minimize environmental damage. This step in the mining process is critical to ensuring the sustainability of the land for future use. First, waste dumps are contoured to flatten them out and stabilize them, covered with soil, vegetation is planted, and the area is fenced to prevent livestock from eating the newly planted vegetation.

Repurposing: As an alternative to the reclamation process, In this method the closed/abandoned/discontinued mines are being modified with advanced technologies and methods such that the mines are repurposed for storage of gases and liquids, Pumped storage Hydropower (PSH), Pumped Underground Storage Hydropower (PUSH), Hydrogen Storage, Renewable Energy, Water disposal, Water storage and flood protection, Tourism, Wildlife Habitat, Pisciculture, Horticulture, etc. depending on multiple factors. This process is often undertaken to address environmental, economic or social concerns.

1.2. Global Landscape of Repurposing of Coal Mines

In the last leg of the mine life cycle i.e. mining closure, the status of the mines falls under any of the following:

Explanation of abandoned/closed/ discontinued mines.

- Discontinued Mines: Discontinued mines mean such working in a mine as have been discontinued for any reason and are inaccessible or rendered inaccessible but are likely to be worked again. These mines can be re-opened as per provisions under (CMR-2017, Reg. 6) and Colliery Amendment Rule-2021 (Rule No 9 (ii)).

- Abandoned Mines: Abandoned mines mean such working as have been abandoned with no intention of working in the future for which the owner of the mine has already submitted a notice to the chief Inspector of Mines, Regional Inspector, and District Magistrate about abandonment in prescribed format (Reg. 5, CMR-2017).
- Closed Mines: Closed mines are those mines for which the owner/agent/manager has submitted notice of closure in prescribed format (under CMR-2017, Reg 5) to the Chief Inspector of Mines, Regional Inspector and district Magistrate and has also obtained the mine closure certificate from Coal Controller (As per mine closure guidelines-2020) and the mines whose extractable reserve as per mining plan has been exhausted.

There are well over a million abandoned mines around the world (some sources believe there are likely to be several million), in all sorts of environments. Some are in extremely fragile areas where a mining license probably wouldn't be granted today. Others are in rare ecosystems found nowhere else on the planet and again, probably where mining wouldn't be permitted today[4].

The US has some 500,000 abandoned mines. There are over 60,000 in Australia whilst it's estimated Canada has at least 10,000. The UK and China have at least 1,500 and 12,000 old coal mines respectively without taking into account all the other types of mines. The Philippines also have around 800[5] abandoned coal mines. Various countries like USA, China, Germany, UK, Australia, Spain have repurposed abandoned mines into recreational parks, established renewable energy sources, and have used the land in a fruitful manner as described below.

For opencast abandoned mines, the likely repurposing options are to generation of energy storage (pumped storage hydropower), generation of renewable energy such as (solar PV, wind, floating solar, geothermal), setting up the mine-ecotourism, and horticulture and pisciculture. While for underground abandoned mines, the likely repurposing options are pumped underground storage hydropower, storage for waste disposal, repurposing for water storage and setting up mine museum under eco-tourism.

Agrivoltaics on Garzweiler Opencast mine, Germany

Garzweiler mine is a lignite mine which is present in the town of Grevenvbroich in Germany. It is owned by RWE Power AG. The mine has been repurposed with Agri-photovoltaic of 3.2 MW output by a big German electricity producer RWE. The demonstration system with an output of 3.2 megawatts was installed on an approximately seven hectare recultivation area on the edge of the Garzweiler opencast mine near Bedburg. RWE wants to test three different forms of application for agri-photovoltaics, i.e. the generation of solar power and agriculture in one area, in the coming years. This involves both arable and horticultural use of the land.[6]

Figure 3: 3.2 MW demonstration plant

Source: PV magazine

Lynnville Park, USA

In 1964, Lynnville Park was established when Peabody Coal Company donated 1100 acres of previously strip-mined land and lakes to the Town of Lynnville. Although the lake is no longer used to provide water supply in the town, but over the years, recreational activities at the park have increased significantly. Presently, the park provides various facilities like 22 primitive sites, 24 modern campsites with water, electric (50 AMP), and sewer hookups, and 16 sites featuring water and electric (50 AMP). The 275-acre main lake houses varieties of fish, including largemouth bass, bluegill, crappie, and catfish. The lake has a handicapped fishing pier, concrete boat ramp, and boat dock. The wooded surroundings is a habitat for diverse wildlife, including quail, whitetail deer, squirrels, rabbits, wild turkey, muskrat, beaver, Canadian geese, songbirds, ducks, and red foxes which are occasionally spotted. The park has evolved into a space, providing a diverse range of outdoor activities for visitors[7].

Coal Mines to Floating Solar Farms, China

Huainan, situated in Anhui Province in eastern China is renowned for its coal industry, has garnered global attention for leading China's shift toward a low-carbon economy. In 2017, the world's largest floating solar power plant was commissioned near Huainan, repurposing a flooded coal mining area. Developed by a renewable energy project developer, China Energy Conservation and Environmental Protection Group (CECEP), a state-owned energy conglomerate, the initiative is backed by the government to address environmental damage caused by coal mine overexploitation. The flooded area is spread across 148.4 hectares of which the floating power plant takes 63.6 hectares. The 70 MW project incorporates nearly 194,700 solar panels, 52,000 float parts and 13 float islands, where the largest island has the approximate capacity of 8.5 MW. The floating power plant is anchored with the lake's silty clay soil bottom, that it is at the most 14.0 meters deep. To accommodate water level fluctuations (up to 4.0 meters) and withstand external hydrodynamic forces like rain and wind, helical anchors stabilize the float parts[8].

Buffalo Mountain Wind Farm, USA

In October 2000, the Anderson County of Tennessee the first commercial wind power plant was installed. A federal corporation, Tennessee Valley Authority (TVA), initiated the project by constructing a three-turbine wind farm on Buffalo Mountain. Once a strip mine site, Buffalo Mountain is a high ridge that is located near Oak Ridge. The mine was operated by the Coal Creek Mining and Manufacturing Company during the 1980s.

Following the mine's closure in 1990, the Coal Creek Mining company undertook reclamation activities, including backfilling and revegetation of the strip-mined areas. When approached by TVA about the prospect of sitting wind turbines on the property, the company took the opportunity for an innovative reuse, generating revenue from an otherwise idle site. The 2 acres wind farm has 660 kW capacity turbines that generate 4,000 MWh annually sufficient to power around 400 homes. The wind farm's development relied on thorough site research, effective community and corporate partnerships, community engagement, and a commitment to emphasizing the significance of renewable energy[9].

Leipziger Land Solar Power Plant, Germany

The plant, situated in Espenhain, Germany, was built on a 49-acre land as a 5 MW photovoltaic plant. The plant consists of 33,500 solar modules, and the electricity generated is directly fed into the German electricity grid. The project was developed and initiated by GEOSOL for USD 26.5 million and is operational from 2004.

The site was a former lignite ash and dust mine, a type of brown coal, and due to site contamination, no other repurposing option was viable. The solar plant was also set up after addressing the on-site contamination. The modules have been set up in an innovative method of wood framing. The wood used for the frames belongs to a local tree, Robinia, and the special characteristic of this wood is, that it is almost indestructible and can withstand all kind of weathers[10].

Drilling disused coal mine for geothermal project, UK

The Sunderland City Council has endorsed exploratory drilling for a project aiming to use water from a defunct coal mine to provide heating for homes and businesses in the eastern UK. The initiative will start near a former coal mine in Wearmouth Colliery that ceased operation in November 1993 and involves borehole drilling to access naturally heated water in a pilot scheme.

If successful, the project could leverage naturally occurring geothermal processes to supply heated water for local households and businesses, potentially reducing their utility bills. The council, having received GBP 1.6 million (USD 2.2 million) from the UK government's Green Heat Networks Fund Transition Scheme, is inviting contractors to express interest in the drilling. The UK's Coal Authority will assist the council in securing contractors[11].

Lake Kepwari, Australia

A coal pit in Collie, Australia, which is a part of a bigger coal mine that produces black coal to power Western Australia's homes and industries, has been repurposed into a lake. The mining operations began around 50 years ago and ceased in 1996. The pit was repurposed and given back to the Collie community and Western Australia Government in 2020 as Lake Kepwari.

The transformation includes revegetation and rehabilitation of 120 ha land around the lake. It took 25 years of study, reporting and monitoring to ensure that the pit transforms into a safe and usable asset. The Lake Kepwari had made the Collie region a tourist attraction spot and provides swimming, fishing and boating for the people[12].

Underground pumped-storage hydro power plants in abandoned coal mines, Spain

The Asturian Central Coal Basin (ACCB) in north of Spain has been exploited for its coal mines for many decades and the network of tunnels extends among more than 30 mines. Parts of the infrastructure was available for alternate uses as most of the underground coal mines in Spain are to be phased out. The network of the tunnels in the closed-down mines is suitable for a possible lower storage for developing an underground pumped-storage project. The infrastructure can hold around 200,000 m^3 at depths that range between 300-600 m[13].

German mines turned into lake district, Lusatia, Germany

Once a coal-mine powerhouse, in the eastern Germany, the industry collapsed with the fall of the Berlin Wall. Later on, 25 lignite mines, open-pit mines of Lusatia were repurposed to recreational lakes. These former mines were filled with water taken from many major rivers including Black Easter and Spree and have drawn 30,000 animals and plants restoring the biodiversity of the region.

Lake Partwitz and Lake Geierswalde have become holiday hot spots. And Lake Partwitz build on a lignite mine in Geierswalde, Lower Lusatia, was fully flooded in 2015 and can be used for swimming and boating purposes. The lake has a clear turquoise color which appears because quicklime was added in the water to neutralize the acidic level of mine[14].

Lavender brightens dirty mine site, USA

Mine sites have high chemical residue in exposed soils and rocks, and it becomes difficult to reforest and restore back the green cover. For that, one option is shipping new topsoil, but that can be quite expensive. But in the coal mining region of West Virginia, one plant was able to flourish in such poor soil condition. The drought-tolerant plant, lavender, is native to dry and rocky soil, and is thus able to grow sustainably in the abandoned mine sites.

Appalachian Botanical Company is harvesting the lavender farm, which is pesticide and chemical free, and processes the lavender oil to be used in culinary and cosmetic products. Harvesting the herb is time consuming and expensive, but it also has accelerated reclamation, hence its beneficial. Apart from these benefits, farming lavender is labor intensive thus providing job to the former miners as well as these plants are covered in honeybees, that act as vital pollinators helping to revive and maintain the biodiversity of the mine site[15].

Fossil fuels to renewable energy, Mongolia

The opencast coal mine of Boortai, situated in Inner Mongolia Autonomous Region of China, was repurposed with 1.12 million solar panel. Previous efforts of regreening the 200 sq km didn’t succeed, hence a solar plant, an alternative ecological means, was adopted to rehabilitate the mine. The old pits are now filled with solar panels, and vegetation thrives underneath the modules, providing double benefit as an economically sustainable option[16].

Big Pit National Coal Museum, UK

An active coal mine from 1880 to 1980, was opened to the public as the Big Pit (Blaenavon) Trust, a charitable trust, in 1983 and later on transformed into a museum in February 2001. A heritage museum situated in Blaenavon, Torfaen, Wales, it is incorporated as the National Mining Museum of Wales, into the National Museums and Galleries of Wales. The museum is dedicated for operational preservation of the Welsh coal mining heritage, that took place during Industrial Revolution.

Before closing down the mine, it was identified as a possible heritage attraction and a working group was set up for the same. After the operations ceased the site was bought by Torfaen Borough Council for GBP 1 and given to a charitable trust, Big Pit (Blaenavon) Trust, to manage the conversion to heritage museum. The initial cost of development was GBP 1.5 million and the funding came from the European Regional Development Fund, the borough council, the Welsh Tourist Board, and Gwent County Council. In 1983, the mine reopened for visitors and created 71 jobs[17].

The above are the few case studies from various countries, where previously active coal mines, after ceasing operations, were transformed into renewable energy source, museums, recreational parks, pit lakes, etc. that generated employment for the locals, ensuring the land is getting utilized for betterment of the community as a whole. As per the case studies given in later section, the ratio of direct to indirect employment generated by various repurposing options ranged from 1:4 to 1:10. And specifically in India, the development process is very organic and not very structured.

2. Overview of Coal Mines in India

Total estimated coal reserve in India as of 1 April 2021 is 352.13 billion metric tons, ranking India at fourth position among all the nations with largest coal reserve in the world. About half of India's coal reserves are proven, 42% are indicated/probable, and 8% are inferred[18]. Coal reserves, of all type of hard coal, non coking and coking, are primarily found in eastern and south-central India. Jharkhand, Orrisa, and Chhattisgarh are major sources of coal reserves in India.

Figure 4: Coal bearing states in India

Source: Ministry of Coal Website

The Ministry of coal is an Indian government ministry, that holds power in determining policies and strategies concerning exploration, production, supply, distribution, and price of coal. Under the administrative control of the Ministry, these key functions are exercised through the Public Sector Undertakings, namely, Coal India Ltd. (CIL) and its subsidiaries including Central Coalfields Limited (CCL), Eastern Coalfields Limited (ECL), Western Coalfields Limited (WCL), Bharat Coking Coal Limited (BCCL), Mahanadi Coalfields Limited (MCL), Northern Coalfields Limited (NCL), Southeastern Coalfields Limited (SECL) and Central Mine Planning and Design Institute (CMPDI)[19]. The coal mines in Assam and its neighboring areas are controlled directly by CIL under the unit Northeastern Coalfields (NEC). The Ministry of Coal also has a joint venture with the Government of Telangana called Singareni Collieries Company Limited. (SCCL), Government of Telangana holds 51% equity and Government of India holds 49% equity[20].

Since nationalization of coal mining in 1973, mining of coal was done only by Coal India Limited and its subsidiaries. Since independence in 1947 till 1973, a structured regulatory body was missing. Nationalization of coal mines were undertaken end the unscientific mining practices and the poor working conditions that the labors faced in the private coal mines. The Government took over all the coking coal mines on October 16, 1971 and nationalized them on May 1, 1972, leading to the formation of Bharat Coking Coal Limited Subsequently in 1973 non-coking coal mines were nationalized, and was owned by Coal Mines Authority Limited (CMAL). In 1975 National Coal Development Corporation (NCDC), an authority with the task to explore new coalfields and expedite development of new coal mines, and Coal Mines Authority Limited (CMAL) was merged to form Coal India Limited (CIL) the largest hard coal producer in the world.

In March 2015, Parliament of India enacted the Coal Mines (Special Provisions) Act, 2015 containing provisions enabling the government to allocate coal mines through auctions and permitting private players to mine coal for their own use like cement, steel, power, or aluminum plants. On 20 February 2018, the Cabinet Committee on Economic Affairs (CCEA) permitted private firms to enter the commercial coal mining industry in India breaking the monopoly over commercial mining of coal. Under the new policy, mines will be auctioned to the firm offering the highest premium[21]. First commercial auction allowing private sector companies, such as Vedanta and Adani Enterprises to participate was held on June 18, 2020. Till date, seven rounds of commercial coal auction have been completed in which 92 coal blocks have been auctioned successfully and vesting order have been issued for 74 blocks[22].

2.1. Coal Fields in India

The coal mining practice in India dates back to 1774 by M/s Sumner and Heatly of East India Company in the Raniganj Coalfield along the Western bank of river Damodar[23].There are 44 coal fields in India as per the data gathered from the website of central mine planning and design institute and the details are given in the table below.

Table 1: List of coalfields in India

S.No.	Coal Field	No. of Coal Blocks	Area (Sq. Km)	District	State
1	Auranga	4	240	Latihar	Jharkhand

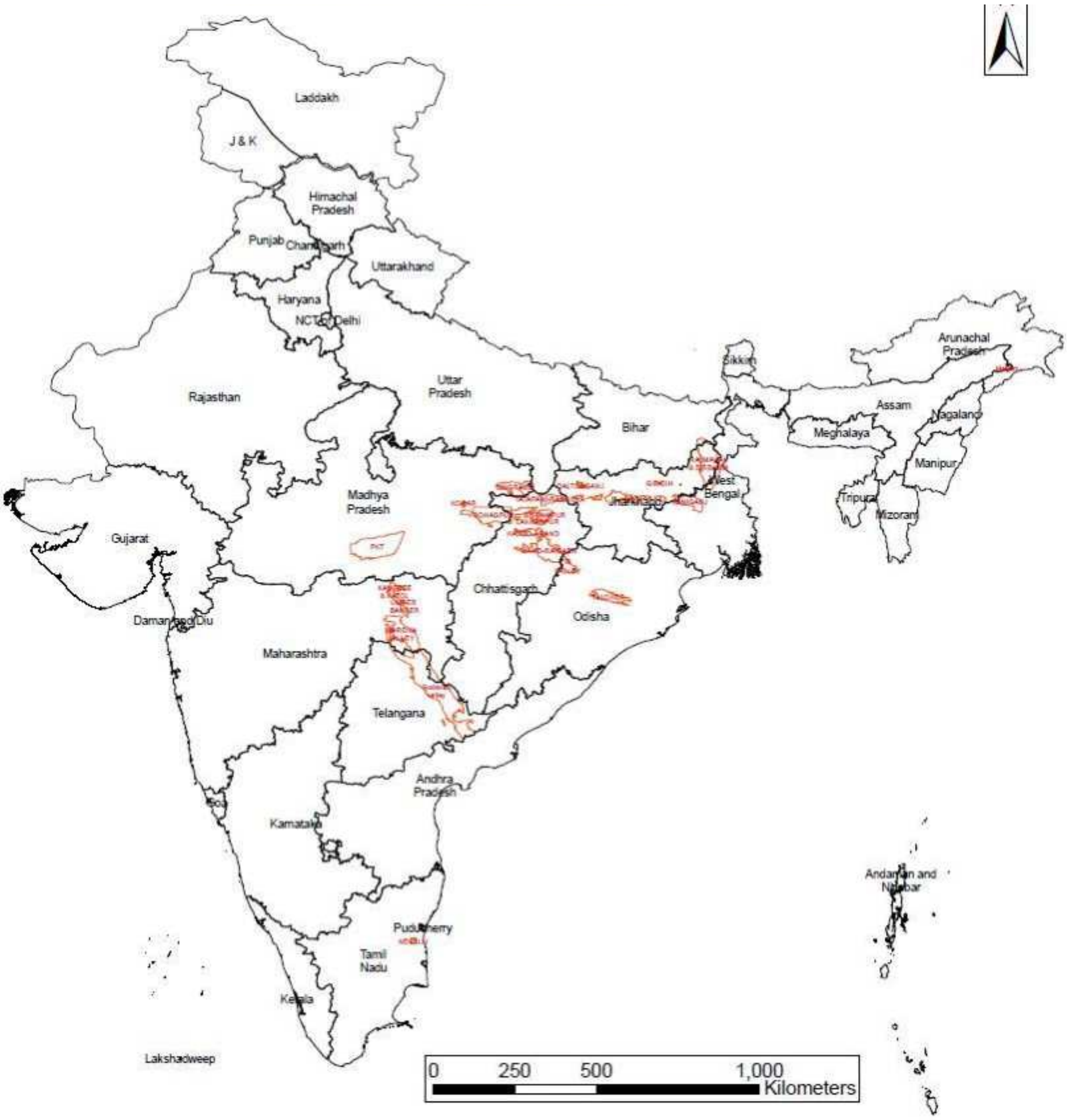
S.No.	Coal Field	No. of Coal Blocks	Area (Sq. Km)	District	State
2	Bander	5	574	Chandrapur & Nagpur	Maharashtra
3	Birbhum	3		Birbhum	West Bengal
4	Bisrampur	15	1289	Surguja	Chhattisgarh
5	Chirimiri	2	180	Manendargarh, chirimiri & bharatpur	Chhattisgarh
6	Daltonganj	6	253	Daltonganj	Jharkhand
7	Dillijeypore	1	24	Dibrugarh & Sivsagar	Assam
8	Dimahasao	1	3	Dima Hasao	Assam
9	EBCF	16	242	Bokaro	Jharkhand
10	Giridih	3	27	Giridih	Jharkhand
11	Godavari	86	15873	Adilabad, Karimnagar, Khammam and Warangal	Telangana
12	Hasdo	5	1549	Surguja, Korba and surajpur	Chhattisgarh
13	Hutar	1	193	Palamu	Jharkhand
14	IBV	27	1316	Jharsuguda	Odisha
15	Jhanzi	1	8.45	Sivasagar & Jorhat	Assam
16	Jharia	31	440	Dhanbad	Jharkhand
17	Jhilimili	3	176	Surguja, koriya, shahdol & umaria	Chhattisgarh & MP
18	Johilla	4	359	Umaria	Madhya Pradesh
19	Kamptee	9	1040	Nagpur	Maharashtra
20	Koilajan	1		Samastipur	Bihar
21	Korar	1	31.61	Kanker	Chhattisgarh
22	Korba	13	1091	Korba	Chhattisgarh
23	Lakhanpur	2	428		Chhattisgarh
24	Makum	4	217	Tinsukia	Assam
25	Mandraigarh	38	3662	Raigarh	Chhattisgarh
26	MIKIR	0			
27	Namchiknamphuk		16		Arunachal Pradesh
28	NKCF	36		Ranchi, Hazaribagh, Chatra & latehar	Jharkhand
29	PKT	21		Chhindwara	Madhya Pradesh
30	Rajmahal	16	5264	Godda	Jharkhand

S.No.	Coal Field	No. of Coal Blocks	Area (Sq. Km)	District	State
31	Ramgarh	6	83	Ramgrah	Jharkhand
32	Raniganj	72	2184	Birbhum, Bankura, Purulia and Dhanbad	Jharkhand
33	Saharjuri	1		Deogarh	Jharkhand
34	Sendurgarh	2	47		Chhattisgarh
35	Singrauli	32	3208	Singrauli, Sonebhadra	Madhya Pradesh
36	SKCF	18			Jharkhand
37	Sohagpur	45	4633	Shahdol	Madhya Pradesh
38	Sonhat	6	1482	Koriya	CHHATTISGARH
39	Talcher	37	2346	Angul	Odisha
40	Tatanpaniramkola	9	1496	Surguja	CHHATTISGARH
41	Umaria	1	145	Umaria	Madhya Pradesh
42	Umrer	2	72	Nagpur	Maharashtra
43	Wardha	44	5326	Chandrapur	Maharashtra
44	WBCF	22		Ramgarh, Hazaribagh	Jharkhand

Source: https://oldsite.cmpdi.co.in/OCBIS/dashboard.php

There are a number of mines present in the coalfields The image below depicts the location of major coalfields in India.

Figure 5: Major coal fields in India



Source: Status report on mine water utilization, June 2021, MoC

As a part of this project, the coal mines data has been extracted from the energy map of India. The data gathered has been compared with the percentage of proven reserve of the respective coal field. The detailed list of the mine is given in appendix A.1.

2.2. List of Closed/Abandoned/discontinued Coal Mines

India has 293 closed/abandoned/discontinued mines as per the ministry of coal notification dated 7 February 2022. These mines have been closed/abandoned/discontinued due to depletion of reserve, spontaneous heating, safety reasons, inundation, adverse techno-economics, financial losses, adverse geo-mining conditions, surface constraints, conversion to opencast mine, etc. Subsidiary wise breakup of these abandoned mine is given below.

Table 2: List of closed/abandoned/discontinued coal mines

Name of the Company	Closed/ abandoned/ discontinued mines
ECL	84
BCCL	42
CCL	29
NCL	1
WCL	56
SECL	66
MCL	2
NEC	4
SCCL	9
Total	**293**

Source: https://www.pib.gov.in/PressReleasePage.aspx?PRID=1796211

2.3. Subsidiary Wise List of Closed/Abandoned/Discontinued Coal Mines of CIL

We have identified a list of abandoned mines in different subsidiaries of CIL and SCCL from the report published by sustainable development cell of ministry of coal in June 2021. In this section we have also captured the mine name, district, annual average mine water availability, district and state.

2.3.1. Bharat Coking Coal Limited (BCCL)

Table 3: closed/abandoned/discontinued coal mines of BCCL

S.No.	Mine	Annual average mine water availability (LKL)	District	State
1	ABGC	43.8	Dhanbad	Jharkhand
2	Maheshpur	3.12	Dhanbad	Jharkhand
3	AKWMC	15.14	Dhanbad	Jharkhand
4	Salanpur	3.28	Dhanbad	Jharkhand
5	Mudidih Colliery	33.22	Dhanbad	Jharkhand
6	Kankanee	10.4	Dhanbad	Jharkhand

S.No.	Mine	Annual average mine water availability (LKL)	District	State
7	SendraBansjora	13.03	Dhanbad	Jharkhand
8	Loyabad	9.5	Dhanbad	Jharkhand
9	East Basuriya	8.51	Dhanbad	Jharkhand
10	Gopalchak Colliery	27.85	Dhanbad	Jharkhand
11	KV 5/6 Pit	96.65	Dhanbad	Jharkhand
12	DobariOCP	2	Dhanbad	Jharkhand
13	Bera Colliery	1.84	Dhanbad	Jharkhand
14	Bastacolla Colliery	3.94	Dhanbad	Jharkhand
15	Asp Collery	17.11	Dhanbad	Jharkhand
16	Murlidih 20/21 Pits Colliery	64.61	Dhanbad	Jharkhand
17	Damagoria Colliery	4.96	Paschim Bardhman	West Bengal
	Total	**358.96**		

Source: Status report on mine water utilization, June 2021, published by MoC

2.3.2. Central Coalfields Limited (CCL)

Table 4: closed/abandoned/discontinued coal mines of CCL

S.No.	Mine	Annual average mine water availability (LKL)	District	State
1	Bokaro OCP	111.35	Bokaro	Jharkhand
2	AKK OCP	0.18	Bokaro	Jharkhand
3	KSP Ph-II	1.5	Bokaro	Jharkhand
4	Kargali OCP	16.66	Bokaro	Jharkhand
5	Kabribad OCP	9	Giridih	Jharkhand
6	Kathara	101.34	Bokaro	Jharkhand
7	Govindpur OC	42.75	Bokaro	Jharkhand
8	Sawang Pipradih OC	20.48	Bokaro	Jharkhand
9	Dhori OC	6.29	Bokaro	Jharkhand
10	SDOC	9.94	Bokaro	Jharkhand

S.No.	Mine	Annual average mine water availability (LKL)	District	State
11	Tarmi OC	3.53	Bokaro	Jharkhand
12	Amlo	22.86	Bokaro	Jharkhand
13	Piparwar	11.25	Chatra	Jharkhand
14	Rohini OCP	2.95	Ranchi	Jharkhand
15	Dakra OCP	0.05	Ranchi	Jharkhand
16	Purnadih OCP	2.27	Ranchi	Jharkhand
17	Old Karkatta	15	Ranchi	Jharkhand
18	Kedla OCP	42.83	Ramgarh	Jharkhand
19	Parej	0.05	Ramgarh	Jharkhand
20	Tapin North	12	Ramgarh	Jharkhand
21	Jharkhand	1.83	Ramgarh	Jharkhand
22	Tapin South	12	Ramgarh	Jharkhand
23	Gidi-A	192.25	Hazaribagh	Jharkhand
24	Gidi-C	21.45	Ramgarh	Jharkhand
25	Religara	12.85	Ramgarh	Jharkhand
26	Old Argada OCP	234	Ramgarh	Jharkhand
27	Bhurkunda	144.81	Hazaribagh	Jharkhand
28	Mini Saunda	4.1	Hazaribagh	Jharkhand
29	KK Colliery	13.7	Hazaribagh	Jharkhand
30	Pindra	1.2	Ramgarh	Jharkhand
31	Topa	30.6	Ramgarh	Jharkhand
32	Pundi	11.8	Ramgarh	Jharkhand
33	Karma	1.5	Ramgarh	Jharkhand
34	Sarubera	10.4	Ramgarh	Jharkhand
35	Ara	31.5	Ramgarh	Jharkhand
36	Rajrappa	0.5	Bokaro	Jharkhand
	Total	**1156.77**		

Source: Status report on mine water utilization, June 2021, published by MoC

2.3.3. Eastern Coalfields Limited (ECL)

Table 5: closed/abandoned/discontinued coal mines of ECL

S.No.	Mine	Annual average mine water availability (LKL)	District	State
1	Purushottapur OCP	72.38	Paschim Bardhman	West Bengal
2	Madhujore UG	3.27	Paschim Bardhman	West Bengal
3	Lachipur UG	5.91	Paschim Bardhman	West Bengal
4	Parasea Old (Dhandadihi)	7.32	Paschim Bardhman	West Bengal
5	Amdiha Quarry	20.35	Paschim Bardhman	West Bengal
6	Dalmia Quarry	28.75	Paschim Bardhman	West Bengal
7	SSI	20.28	Paschim Bardhman	West Bengal
8	Girmint	22.08	Paschim Bardhman	West Bengal
9	Mithapur	7.12	Paschim Bardhman	West Bengal
10	Kuardih/Tirat	20.31	Paschim Bardhman	West Bengal
11	Jemehari	11.95	Paschim Bardhman	West Bengal
12	Ghanashyam Old OCP	22.5	Paschim Bardhman	West Bengal
13	Mahabir OCP	8.86	Paschim Bardhman	West Bengal
	Total	**251.08**		

Source: Status report on mine water utilization, June 2021, published by MoC

2.3.4. Mahanadi Coalfields Limited (MCL)

Table 6: closed/abandoned/discontinued coal mines of MCL

S.No.	Mine	Annual average mine water availability (LKL)	District	State
1	Chhendipada	9.5	Angul	Odisha
2	Talcher Colliery	36.82	Angul	Odisha
3	Deulbera Colliery	16.77	Angul	Odisha
4	Handidhua Colliery	25.79	Angul	Odisha
5	Orient Colliery UG Mine No.4	9.76	Jharsuguda	Odisha
6	Rampur Colliery UG	6.97	Jharsuguda	Odisha

S.No.	Mine	Annual average mine water availability (LKL)	District	State
7	Lilari OC	7.45	Jharsuguda	Odisha
8	Basundhara East	31.55	Sundergarh	Odisha
	Total	**144.61**		

Source: Status report on mine water utilization, June 2021, published by MoC

2.3.5. South Eastern Coalfields Limited (SECL)

Table 7: closed/abandoned/discontinued coal mines of SECL

S.No.	Mine	Annual average mine water availability (LKL)	District	State
1	Kalyani U/G	4.33	Surajpur	Chhattisgarh
2	Somna UG Mine	1.53	Anuppur	Madhya Pradesh
3	Palkimara UG Mine	5.25	Korea	Chhattisgarh
4	B Seam UG Mine	9.19	Korea	Chhattisgarh
5	Malga UG Mine	0	Anuppur	Madhya Pradesh
6	North JKD	2.04	Korea	Chhattisgarh
7	Navgaon UG	3.35	Shahdol	Madhya Pradesh
8	Bishrampur OCM	28.01	Sarguja	Chhattisgarh
9	Banki U/G	15.38	Korba	Chhattisgarh
10	Dharam U/G Mine	2.19	Raigarh	Chhattisgarh
	Total	**71.27**		

Source: Status report on mine water utilization, June 2021, published by MoC

2.3.6. Western Coalfields Limited (WCL)

Table 8: closed/abandoned/discontinued coal mines of WCL

S.No.	Mine	Annual average mine water availability (LKL)	District	State
1	Ghorawari OC	2.8	Chhindwara	Madhya Pradesh
2	Nandan UG	2.33	Chhindwara	Madhya Pradesh
3	Damua UG	2.33	Chhindwara	Madhya Pradesh
4	Jharna UG	0.75	Chhindwara	Madhya Pradesh
	Total	**8.21**		

Source: Status report on mine water utilization, June 2021, published by MoC

2.3.7. Singareni Collieries Company Limited (SCCL)

Table 9: closed/abandoned/discontinued coal mines of SCCL

S.No.	Mine	Annual average mine water availability (LKL)	District	State
1	No.21 Incline Mine, Yellandu	2.92	Bhadradri Kothagudem	Telangana
2	Bore water-Old UG workings of JK 5 Incline	5.56	Bhadradri Kothagudem	Telangana
3	2 Incline Mine,Bore holes,5B Incline, 5 Shaft & VK 7 Incline	17.4	Bhadradri Kothagudem	Telangana
4	MVK-1and MVK-3 Inclines	3.29	Kumuram Bheem (Asifabad)	
5	Goleti-1 Incline	3.52	Kumuram Bheem (Asifabad)	Telangana
6	KK-2 Incline	1.65	Mancherial	
7	GDK 10 & 10A Incline	3.66	Pedapalli	Telangana
	Total	**38**		

Source: Status report on mine water utilization, June 2021, published by MoC

3. Status Quo of Reclamation and Repurposing of Coal Mines in India

India is known for its diversity, and that diversity can be seen in the different mines that are present in India. Apart from coal mines, there are mines and ores for diamond, gold, iron, manganese, bauxite, copper, lead, etc. and just like coal mines, these mines also get depleted after a point, leaving the option to repurpose them in a way that benefits the environment, people and society.

There are numerous abandoned/closed mines out there that are left idle, but some of them have been repurposed and are either generating revenues or are providing environmental benefits or both. And since all the mines are either open cast or underground, the repurposing options that these mines are implementing can be implemented in the identified abandoned coal mines as well. Listed below are some examples of repurposing of mines that have happened or will happen in future in India.

Proposed 'Just Transition' for Korba mine

Just Transition in simple words means ensuring a green economy that is inclusive and is fair, to the extent possible, to everyone that leaves no one behind and creates decent employment opportunities.

The just transition has to take into accounts various aspect to be in place efficiently.

- By 2070, India is targeting net-zero emission, thus the coal power plant and the coal mines needs to close by 2040 and 2050 respectively, without any disruption.
- For formal workers, securing pension funds, and skilling new workers is important; and for informal workers, infrastructure investment and government support is important. The informal workers are mostly semi-skilled and unskilled, thus the government support must provide livelihood generation schemes and employment generation. Both the central and the state governments must ensure that they are provided the required training so that they can be reemployed. And the government must invest in building new infrastructure and industries ensuring job creation.
- Economic diversity should have a balanced contribution to the district's GDP from the primary, secondary and tertiary sectors.
- Planning a proper and diversified (in terms of environment, economic, and social impact) repurposing and reclamation of the 10,000 hectares of the mines. Scientific closure and repurposing mining land, particularly the opencast mines, has significant potential for economic activities. As the available land can be used to develop industries like, not limited to , tourism, fisheries, horticulture, value-added agriculture and service sector. These can be used for industrial development like low-carbon industries and renewable energy, say setting up solar parks among others.
- Availing funds by pooling the coal cess, DMF, and CSR funds over three decades for the smooth transition.
- Participatory approaches in the planning process to ensure inclusivity and incorporate the wishes of people in the region. Previous global experiences of coal mine closures show that planning a top-down approach has not resulted in successful transition outcomes. It has been underscored by UN that an inclusive just transition plan should be developed as

- Developing inclusive planning and execution mechanisms garners broad-based support.
- Implementing top-down approach will hinder the social acceptance of just transition.
- Assessing the aspirations and needs of people is crucial, for effectiveness of the transition plans and investments.

Thus, a structured approach is required that will consider phasing down and closure of the coal mines and the power plants, and simultaneously implement an integrated and inclusive restructuring plan that helps in net positive social, environmental and economic outcomes[24].

Nandini forest on limestone mine

Situated 55km from Raipur, in Durg district, Nandini forest will be the largest man-made forest, developed on an abandoned mine of limestone. The initiative is to convert the unproductive land stretched across 3777 acres of land into a natural habitat. Till 2021, 1120 acres of land was transformed into a jungle, and that year 83,000 sapling of 30 different species that includes medicinal plants as well were planted on 895 acres of land.

The environment conservation initiative is based on a Japanese technique, Miyawaki, where the plants have natural muti-layered growth, thus creating a dense self-sustaining native forest[25].

Biodiversity park in bauxite mine

A Mumbai based company, Hindalco Industries Limited, as a sustainable mining development effort, has reclaimed 5-hectare land in Bagru hills, a bauxite mine, situated in Lohardaga, Jharkhand, to build a biodiversity park. The park has a butterfly garden, and the plantation includes herbs, flowering plants, medicinal plants, trees bearing seasonal fruits and vegetables, and produces tea as well.

As a land reclamation measure, for every patch of land mined, the topsoil is preserved, and once mining is done on the patch, the land is backfilled with overburden and the topsoil is put back in place. A symbiotic fungus, developed by Hindalco and Institute of Forest Genetics and Tree Breeding, VAM is used for nurture back the fertility and health of the topsoil.

Few of the lands are deliberately left void, and a pond is created through rainwater harvesting where locals have adopted pisciculture and duck farming to add increase their household incomes[26].

Energy generation from gold mine

Green Gravity, Australian renewable-energy generation company, plans to use weighted block and gravity to generate electricity in the Kolar Gold Fields (KGF) of Karnataka. A weighted block will be hauled when the renewable energy is present, and in absence of the renewable energy, weighted block will be released and will be pulled down due to gravity generating momentum to power the generator or turbine. The power generation is controlled by controlling the fall of the block though braking systems.

This technology can be setup in defuncted mines, ensuring no adverse environment affect, providing employment generation, and generating electricity when renewable energy is not present[27].

Abandoned coal mine to tourist spot

An abandoned quarry in Bishrampur, a town in Chhattisgarh, has been repurposed as an ecotourism spot. The different experiences that a tourist can enjoy in the facility include boat riding, floating restaurant, overnight stay, and pisciculture is also practiced in the lake, where fish are bred in underwater cages.

The place is run by local administration, and they are planning to hand over the place to the tourism department of the state, so the site operates in a professional manner and generates more employment for the locals[28].

This site is one of the examples where Coal India has converted 30 abandoned mines into eco-tourism spots and eco-parks. The aim is to ensure employment generation for the locals and improving the area's green cover. These parks have been able to attract visitors, encouraging the authorities to convert more mines into ecotourist sites and eco-parks. Gokul ecocultural park of BCCL, Chandra Sekhar Azad eco park of CCL, AnanyaVatika and Kenapara ecotourism spot of SECL, Mudwani eco-park and Krishnashila eco restoration site of NCL, BalGangadhar Tilak eco park of WCL, Ananta medicinal garden of MCL, and Gunjanpark of ECL are names of few of such mines[29].

Pit lakes on abandoned coal mine

Pit lakes formed in abandoned mines store large amounts of water, supporting the drinking and daily requirements of the local community. These pit lakes formed in the mines of Jharkhand and West Bengal attract numerous migratory birds who arrive there to rest and refuel themselves. The harbor provides alternative source of water at places where there is scarcity of water[30].

Abandoned coal mine used for fish farming

In west Singhbhum, a district of Jharkhand, the district administration generated livelihood by using the abandoned mines for pisciculture. This has helped the youth of the area to become self-reliant and ensured that they had a proper source of income. The scheme was introduced during the COVID when people started coming back and had no source of livelihood to sustain themselves.

People started fish farming in cages that generated a stable income for people living in the nearby regions also. These water bodies are also being used for boat rides bringing in additional income to the people[31].

Once a mine now a wildlife sanctuary

Asola-Bhati Wildlife Sanctuary sits on the Southern Delhi Range of the Aravalli hills. Spread across 32.71 sq km, the sanctuary is a home to 193 different species of birds, 80 species of butterflies, numerous insects, and various mammals like nilgai, leopards, blackbuck, small Indian civet, Indian crested porcupine, black-naped hare, jungle cat, golden jackal, etc.

Previously this mine was known for illegal mining of stone and red Badarpur sand used for construction. But in 2000, the Department of Environment, Delhi government commenced a rehabilitation program of the Bhatti mines spread across 2,100 acres[32].

Solar power plant by SCCL

Singareni Collieries Company Limited (SCCL) has envisaged an 800 MW solar power plant, including 500 MW floating solar in Telangana. Of the 300 MW, the company is planning to complete 129 MW capacity under Phase-I. And of the 129 MW till now it has completed 30 MW at Manuguru and 10 MW at Jaipur.

The Manuguru plant has been constructed on an area of 150 acres near Manuguru village at a cost of INR 125 crore[33].

Wind farm on lignite mine

Neyveli Lignite corporation (NLC) India Limited has set up a 51 MW wind power generation plant at Kaluneerkulam, Tamil Nadu. The project was setup by formerly Leitwind Shriram Manufacturing Ltd now LSML and was commissioned in 2014 in the month of August. The project consists of 34 units of LTW80 - 1.5 (Leitwind Shriram) turbines, each with 1.5MW nameplate capacity[34].

Proposed geothermal power plant

SCCL is planning to set up a geothermal plant in Pagideru of Manuguru, an area in the Bhadradri district of Telangana. It will a first of its kind and will be set up by the company in collaboration with Union Ministry of Coal's, Department of Science and Technology at a cost of INR 1.72 crore[35].

Proposed green hydrogen from lignite and coal mine

According to the Ministry of Coal, there will soon be availability of vast amounts of land as coal is phasing out gradually. Even 10% of the land will be able to produce 1 million MT of hydrogen annually. India consumes 7.5 MT of hydrogen annually. Thus, reclaiming and repurposing these coal mines for hydrogen production is very cost efficient as requirements like land and fresh water are fulfilled and existing infrastructure and resource will be utilized for hydrogen generation. It will also provide employment generation for people for whom these coal mines are the sole source of income (if reskilling measures are provided for)[36].

Proposed pump storage plant

The Ministry of Coal has plans to set up pump storage plants in abandoned mines. The aim is to diversify alternative sources of energy. Through this project, it plans to use solar power to develop hydroelectricity. The main focus of the initiative is to use solar energy to generate power during the day and use hydroelectricity at night. The initiative will help to promote sustainable development in this sector. Coal India Limited (CIL) has identified 20 abandoned mines for the project[37]. CIL will conduct feasibility study for the identified 20 mine sites for establishment of pumped storage hydropower plant for generation of electricity.

In this water stored in the abandoned coal mines will be lifted through solar energy, reservoirs will be constructed where this lifted water will be stored and at night this water will be used for generating hydroelectricity[38].

Goa to use abandoned mines for pumped storage and floating solar

The state plans to go to 100% renewable energy by 2050 for all the sectors in the state. As a result of this decision, the state government is exploring the possibilities of using abandoned mines in the state to set up floating solar units and pumped storage units. As of now the state is attempting to achieve 50% renewable energy by 2030 for all the sectors.

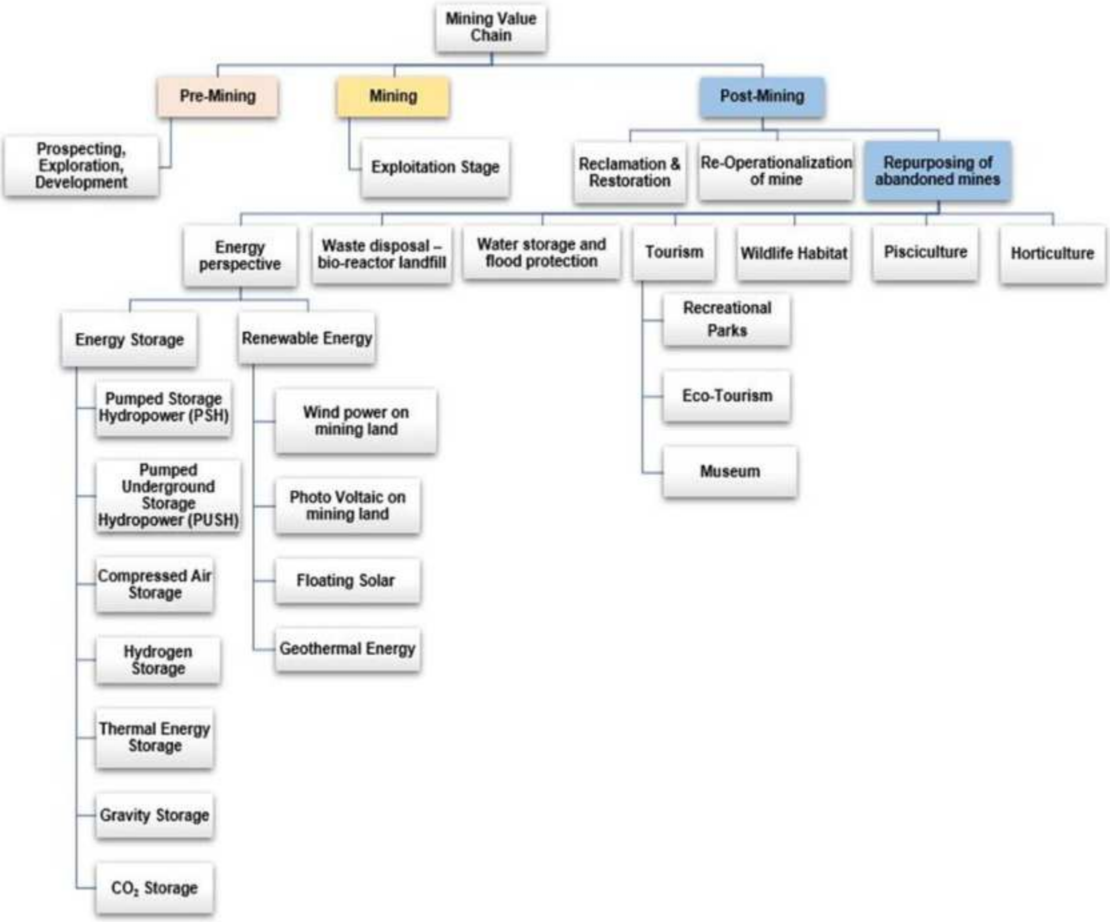
The state has peculiar geographical topography and limited land to set up solar farms on ground. Thus, it wants to efficiently use any available land and is planning to use the abandoned mines to be self-reliant and have sufficient renewable energy to meet its requirements[39].

To conclude, there are various repurposing options that are already in place, and a few have been proposed for the abandoned mines, be it coal mine, gold mine, bauxite mine, or limestone mine. The repurposing options that are already operational have been detailed out in the later sections. Based on those sections it can be decided which option is suitable for what type of mine.

4. Assessment of Repurposing Options

Repurposing is to be seen as an important part of the mining value chain which comes into play in post mining scenario. There are multiple repurposing options that can be practiced on a mine site and are being researched upon. There are various categories in which these repurposing options can be clubbed like energy storage, renewable energy, waste disposal, water storage, tourism, wildlife habitat, pisciculture, and horticulture. Each of the repurposing options identified in the schematic diagram given below is explained in the later sections.

Figure 6: Schematic diagram of repurposing options



Source: PwC Analyses

5. Pumped storage hydropower and pumped underground storage hydropower - As a Repurposing Option

5.1. Introduction to repurposing option

The global effort to decarbonize electricity systems has led to widespread deployments of variable renewable energy generation technologies, which in turn has boosted research and development interest in bulk Electrical Energy Storage (EES)[40]. Because most low-carbon electricity resources cannot adjust their output to match fluctuating power demands, there is an increasing need for bulk electricity storage to maximize the benefits from renewable energy. This technology can be the backbone of a reliable renewable electricity system. Pumped Hydroelectric Energy Storage (PHES) is a tried, tested and proven option for providing bulk EES (with a global installed capacity of around 130 GW) and has been an integral part of many electricity networks since the 1960's.

Pump Storage Power plants (PSP) or referred as Pumped Hydroelectric Energy Storage (PHES) or Pump Storage Hydropower (PSH) are similar technologies. Pump Underground Storage Hydropower is a little different than PSH/PHES/PSH as explained in following paragraphs. The two options that are useful options for repurposing mines: Pumped storage hydropower (PSH) and Pumped Underground Storage projects (PUSH). Pumped storage is widely regarded as one of the most reliable, cost-effective, and mature technologies for large-scale energy storage, and using coal mines that are either abandoned or slated for closure is a promising opportunity.

Pumped storage hydropower (PSH) is a highly versatile power generation system frequently employed for energy storage and grid optimization. One of its possible future standout features is its' adaptability for repurposing of existing infrastructures such as abandoned mines, quarries, or reservoirs. Though, the transformation of these sites into PSH facilities involves a dynamic process influenced by specific regional requirements, local regulations, environmental considerations as well as the mine configuration, its current state and adaptability to the changing operational requirements.

The process of coal mining naturally results in large quantities of both open pit excavations and underground caverns. Pumped Storage Hydro (PSH) projects utilize open pit mines which already provide reservoirs. One of the deciding factors of which mines is fit to use as PSH is a significant and useable elevation difference. Pumped Underground Storage projects (PUSH) typically use existing deep underground coal mine workings that can be developed as a lower reservoir. In both cases, the restored surface areas of old coal mines can be effectively repurposed as sites for wind and solar farms, ensuring a sustainable and renewable power supply for PSH and PUSH. This integration of renewable energy generation and energy storage has the potential to unlock new opportunities for the coal industry. Most pumped storage hydropower projects are designed as closed-loop systems, operating independently from naturally flowing water bodies. This design allows the direct utilization of mine water as an independent source mitigating the risk of water contamination of other important critical water resources.

5.2. Global best practices with examples

On a global scale, many countries are in the process of phasing out coal power plants for several compelling reasons, including their aging infrastructure, dwindling profitability and the mounting negative environmental impacts associated with their operation[41]. Europe in particular, has made significant strides in this transition, with Germany, a former heavy coal consumer following the United Kingdom and France with retiring coal plants[42,43]. Beyond Europe, Canada and the United States have also taken measures to shut many of their coal facilities and are seeking productive alternative uses for these sites. The systematic integration of renewable energy, encompassing solar, wind, and pumped storage hydropower offers benefits for power system management. The innovative utilization of abandoned mine facilities for pumped storage hydropower projects can enhance this process. It not only provides benefits in terms of power generation and grid stability but also can have positive social and environmental impacts that assist in bolstering the economic stability of the region.

Because there are only a few examples of repurposing and converting abandoned open pit coal mines for hydropower (PSH) it is a relatively new frontier and the practical execution of such projects remains challenging. The lack of precedent practice, particularly in the case of projects with underground lower reservoirs (PUSH), and the scarcity of information on the main hazards and the risks associated with such conversions in terms of the measures necessary to provide operational stability and certainty of generation, needs much more understanding of key issues. Nonetheless, the possibility of repurposing is swiftly gaining prominence, particularly with the emergence of initiatives such as the Powering Renewable Energy Transition.

The basic premise of repurposing coal mines into pumped storage hydropower projects is that it offers a sustainable and innovative approach to transforming disused mine sites into renewable energy sources. Some of the key issues in repurposing coal mines into pumped storage hydropower projects are as follows:

- Identification of suitable locations for conversion taking into consideration factors such as the mine's depth, the geology, its current state in terms of the stability of the workings, an assessment of any existing or potential collapses, the proximity to water sources and local and regional grid connections.
- Conducting a feasibility study to assess the technical, economic, and environmental viability of the proposed pumped storage hydropower project.
- Assessing the initiatives required in the environmental cleanup and land rehabilitation efforts to mitigate the site's ecological impact.
- The extent of modifying existing infrastructure, such as tunnels and shafts, to accommodate water flow and turbine equipment.
- Managing water supply either from natural or artificial reservoirs, to provide the necessary water volume for energy storage and generation.
- Managing local communities to build support for a successful project implementation along with the compliance with local, regional, and national regulations.
- Economic sustainability through proper funding mechanisms such as public-private partnerships or government incentives to support the conversion.

By implementing good practices serving as the basis of accepted global coal mine closure standards, the highest value of the closed mine and the associated surface resources can be ensured through a Land Repurposing Methodology (LRM) with the help of GIS applications[44]. The LRM generally includes:

- Stocktaking and site inventory.
- Collation of all records of mine development.
- Clarification of the legal, regulatory and permitting situation.
- Site investigation, testing and monitoring.
- Land classification methodology – by using GIS.
- Land repurposing master plan (LRMP).

The above approach allows a former coal mine to reinstate some previous functions such as the infrastructure and other necessary facilities. As the proportion of variable renewable energy sources continues to rise in global power systems, the ability to reinstate ancillary services formerly supplied by coal mines is becoming increasingly attractive. Additionally, the repurposing of available land and transmission infrastructure represents a valuable opportunity in this evolving energy landscape[45].

For power projects, repurposing offers many advantages.

- It can limit some of the environmental remediation requirements and allow reuse of part of the existing assets such as local substations.
- It reduces the cost of commissioning greenfield renewable energy (RE) capacity at the same site.
- For coal mines located in urban and semi-urban areas, repurposing manifests in multiple end uses, leading to economic diversification benefiting local economies.
- It leads to economic diversification that also benefits local economies.
- Conversion of coal mines into pumped storage hydropower facilities facilitates the integration of renewable energy sources and also provides a reliable and efficient means of balancing the fluctuating nature of renewable energy generation. It acts as a stabilizing force on the grid, ensuring a steady and consistent power supply.

As a new field in developing hydropower, there are a few projects where repurposing of coal mines for PSH has been implemented and available examples are discussed below. While PUSH (deep underground storage) using coal mines is under serious consideration in a number of countries and many of the constraints and key issues involved in such a conversion have been identified there are no known projects currently under active planning with the immediate prospect of moving to development.

The first idea of exploiting a mine as an underground reservoir dated from 1960[46] and several studies and technical reports were produced but not followed up with functioning pilot projects[47]. The Mount Hope project, located in northern New Jersey was initially proposed in 1975. It intended to use the facilities of an abandoned iron mine as a lower reservoir, but it was never developed[48].

The following are some examples of repurposing of mine works using PSH and PUSH (both coal and other commodities). The table given below summarizes the project types and its status.

Table 10: Type of pumped storage project

S. No	Project Description	Status of Pumped storage Hydropower (PSH)	Status of Pumped underground storage hydropower (PUSH)
1	Kidstone Pumped storge project, Queensland, Australia	Both reservoirs are on surface; under construction	
2	Fushun Pumped storage project, China	Both reservoirs are on surface; feasibility study stage	
3	Dinorwig Pumped Storage Scheme in North Wales	PSH with open pit lower reservoir; commissioned	
4	Goaf-PHS system, China		Underground lower reservoir; conceptual Stage
5	Prosper-Haniel, Germany		Underground lower reservoir; under study stage
6	PSH plant at Upper Harz, Germany		Underground lower reservoir; under study stage
7	Asturian coal mine PSH		Underground lower reservoir; under study and research
8	PSH in Indiana		Underground lower reservoir; under study stage
9	Kentucky PSH, USA		Underground lower reservoir; under study stage
10	AML Study USA		Underground lower reservoir; under study stage

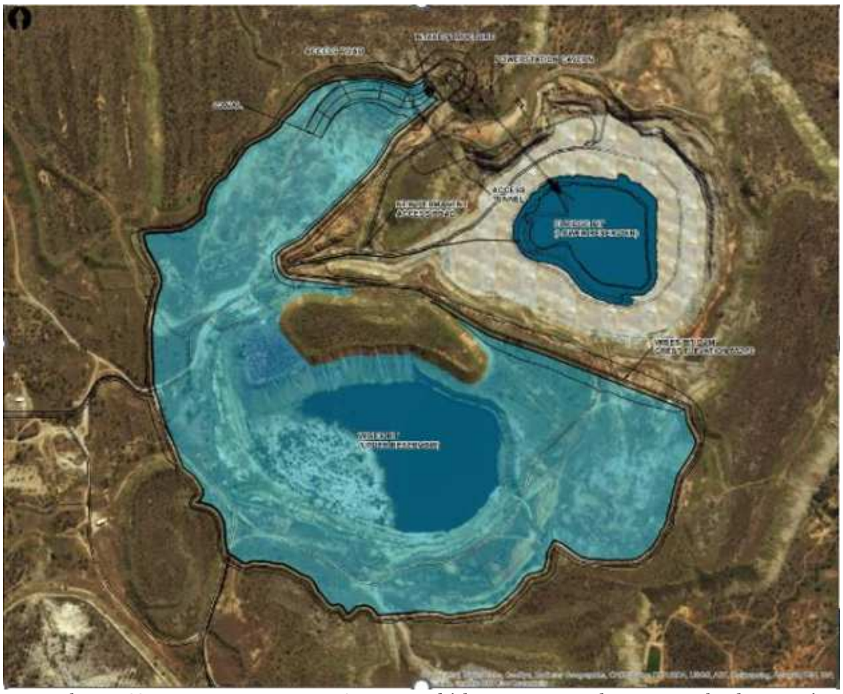
Source: PwC analysis of the gathered data

5.2.1. Pumped storage hydropower

1. **Kidston Pumped Storage Hydro Project**

Construction is underway of an innovative engineering project that will turn two retired mining pits in Queensland into a pumped hydro energy storage facility. Genex Power is developing the 250 MW Kidston Pumped Storage Hydro Project at the old Kidston gold mine, 270 km north-west of Townsville, by using the abandoned mines[49]. The project is planned for commissioning in 2024 and involves building an upper-level dam, or 'turkey's nest', around the top of the uppermost mine pit.

Figure 7: 250 MW Kidston Pumped Storage Hydro Project, Queensland, Australia



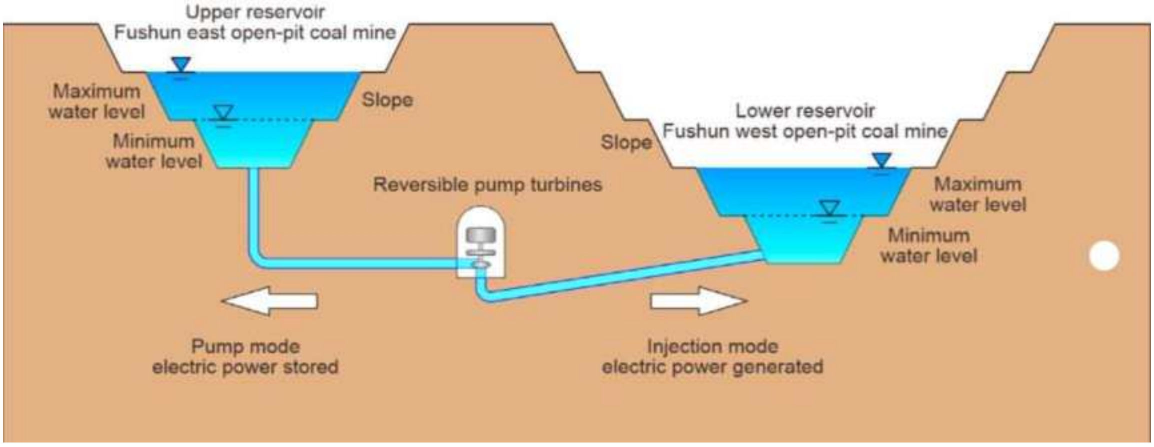
Source: https://genexpower.com.au/250mw-kidston-pumped-storage-hydro-project/

Water stored in this upper reservoir falls some 220 meters down two vertical pressure shafts into a powerhouse with reversible turbine-generators. Energy Australia has entered into a 30-year offtake agreement with Genex who will sell the energy into the National Electricity Market. The facility will have 250 MW generating capacity and energy storage capacity of 2000 MWh in the top reservoir.

2. Fushun West Open-Pit coal mine

In China, the Fushun West Open-Pit coal mine was repurposed to pumped storage hydropower demonstrating abandoned open-pit mines can bring economic, social, and environmental benefits[50]. Based on the engineering background and characteristics of the coal mine, a PSH plant was designed which redeveloped the abandoned pit as the lower reservoir. Fushun East Open pit coal mine making combined use of Nanhuayuan Lake, three dumps, and another open pit were utilized as the upper reservoir. Using the tilt photogrammetry, it has been determined that the cumulative volume and area of the pit is 1019 million m^3, which provides an enormous potential generating capacity. A preliminary estimation shows that the installed capacity of the PSH plant in three phases could reach 40, 3200, and 2,000 MW, and the water levels of the lower reservoir are -295 m, -200 m, and -150 m, respectively.

Figure 8: Schematic of the PSH plant in open-pit mines



Source: Feiyue Liu, Ke Yang, Tianhong Yang, Yuan Gao, Jinduo Li3, Qinjie Liu and Qiang Fu, 2022: Pumped storage hydropower in an abandoned open-pit coal mine: Slope stability analysis under different water levels

3. Dinorwig Power Station

The opportunity to utilize the open pit mine infrastructure in the post mine closure process for the development of pumped storage hydro is not a new concept. A lower open pit slate quarry (Wellington Pool) combined with an existing lake was used as the outfall and part of the lower reservoir in the 1,728 MW Dinorwig Pumped Storage Scheme in North Wales (UK) [51]. Fully commissioned in 1984, the station is a prime example of an abandoned quarry being utilized to develop a pumped storage generation facility. Transforming an existing open mine pit into one of the storage reservoirs has the attraction of not requiring the construction of a new dam. However, as with other PSH technologies, assessing the suitability of a site is not determined by a single factor, there was a suitable natural lake

Figure 9: Dinorwig Power Station – view of the outfall area

Source: https://en.wikipedia.org/wiki/Dinorwig_Power_Station

developed as an upper reservoir that also made the scheme attractive for development.

5.2.2. Pumped underground storage hydropower

1. Michigan Technological University research

In the USA, a group of researchers at Michigan Technological University (MTU) argues that a fully renewable energy grid could be achieved if the US converted mines into hydro-powered batteries. The need for more energy storage has become "absolutely urgent" as renewable energy sources have expanded with wind and solar power generation outpacing our ability to use or store it, creating bottlenecks of pent-up power that can lead to wasted energy and brownouts. Scarlett explains that converting mines to act as batteries would stabilize a grid powered by wind and solar, absorb excess power, and make up for shortfalls at times when there is either too much or too little power.

Such mines could clear the path for the "most ambitious" renewable energy goals in much of the country. The opportunities and barriers for repurposing decommissioned mines into PUSH was examined at MTU's Keweenaw Energy Transitions Lab (KETL), which has as its overarching objective to explore, investigate, and develop pathways for transforming old environmental and economic liabilities into productive clean energy assets for the benefit of sustainable and prosperous communities. The PUSH study focuses on a decommissioned iron ore mine in Negaunee, Michigan, but also extended the results to consider the applicability of PUSH on a national scale.

2. China's Inner Mongolia region

According to Chinese researchers, using abandoned coal mine goaves (another term for deep coal mines) for pumped hydro facilities in combination with large scale solar and wind is not only technically feasible but could also provide an efficiency estimated at 82.8%. They applied the model to wind and solar-rich areas of North-West and South-East China. Researchers from the Chongqing University in China and Chinese investments firm Shaanxi Investment Group Co., Ltd have proposed using abandoned coal mine goaves as upper and underground water reservoirs for pumped underground hydro storage (PUSH) facilities in combination with large-scale solar and wind facilities[52]. "During extraction of mineral resources from underground deposits, shafts and extensive galleries are excavated," the academics explained. "These underground voids are usually left to be flooded, but often perpetual costs related to pumping to keep a safe water level or water treatment have to be maintained, becoming long-term liabilities."

Figure 10: A coal mine in China's Inner Mongolia region

Source Ref: https://www.pv-magazine.com/2021/11/16/how-to-convert-coal-mine-goaves-into-pumped-hydro-storage-facilities/

According to the analysis of Researchers from the Chongqing University in China, currently there are 3,868 closed coal mines in China that in the long term could be considered for this repurposing concept. To assess if these sites are suitable for PUSH, three main aspects are considered: storable volume; usable volume; and fluid exchange. Once these values are determined, the performance of a goaf pumped-hydro storage facility can be evaluated by considering meteorological data such as solar radiation and wind speed. Using a lower reservoir located at the underground mine goaves, the ideal minimum altitude difference between the upper and lower reservoir is indicated at around 100m.

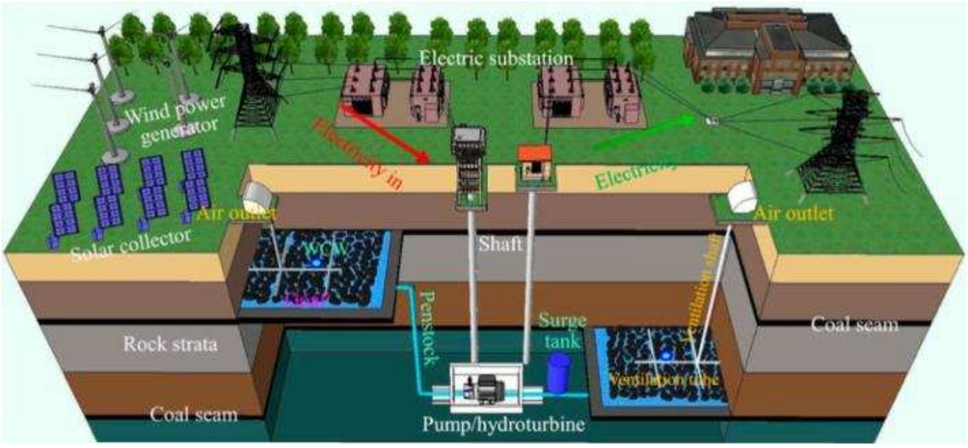
The proposed system (PUSH) would rely on conventional components such as reversible hydraulic pumps, turbines, and penstocks, and operated in combination with conventional utility-scale wind and solar power plants. "When the electricity generated by wind and solar power cannot satisfy the demand, the stored water will be released to produce electricity and fill the demand gap," the Chinese group explained. "The penstocks, surge tank, and a variety of connecting tunnels/rooms provide ancillary services for the system's smooth operation."

The scientists emphasized that the storage capacity of a similar scheme would depend not only on the goaf volume but also on the interspace between the fractured rock blocks (due to relaxation and loosening) that occur within the goaf itself after mining activities are abandoned. "During charging and discharging, water and air would exchange, and the permeability within the goaf determines whether the water or air can flow in and out smoothly or not," they said, noting that the flow velocity of water and air within the reservoir is determined by pressure gradient and permeability.

"To ensure sufficient outputs of turbine and pumps, the maximum water flow should be guaranteed," they added. "As the permeability decreases, the saturation line tends to decline during injection and rise during releasing, implying a less water volume injected during filling and released during draining the reservoir, and hence a smaller usable capacity of the goaf reservoirs." The system design also includes the construction of ventilation shafts 2m above the maximum water level in the reservoir for smooth air exchange during either pumping or gravitational flow.

The regulated energy per volume (REPV) is estimated at 2.82 kWh/m3.

Figure 11: Pumped hydro storage system using abandoned coal mine goafs



Source: Deyi Jiang, Shao Chen, Wenhao Liu, Yiwei Ren. Pengyv Guo, Zongze Li: Underground Hydro-Pumped Energy Storage Using Coal Mine Goafs: System Performance Analysis and a Case Study for China

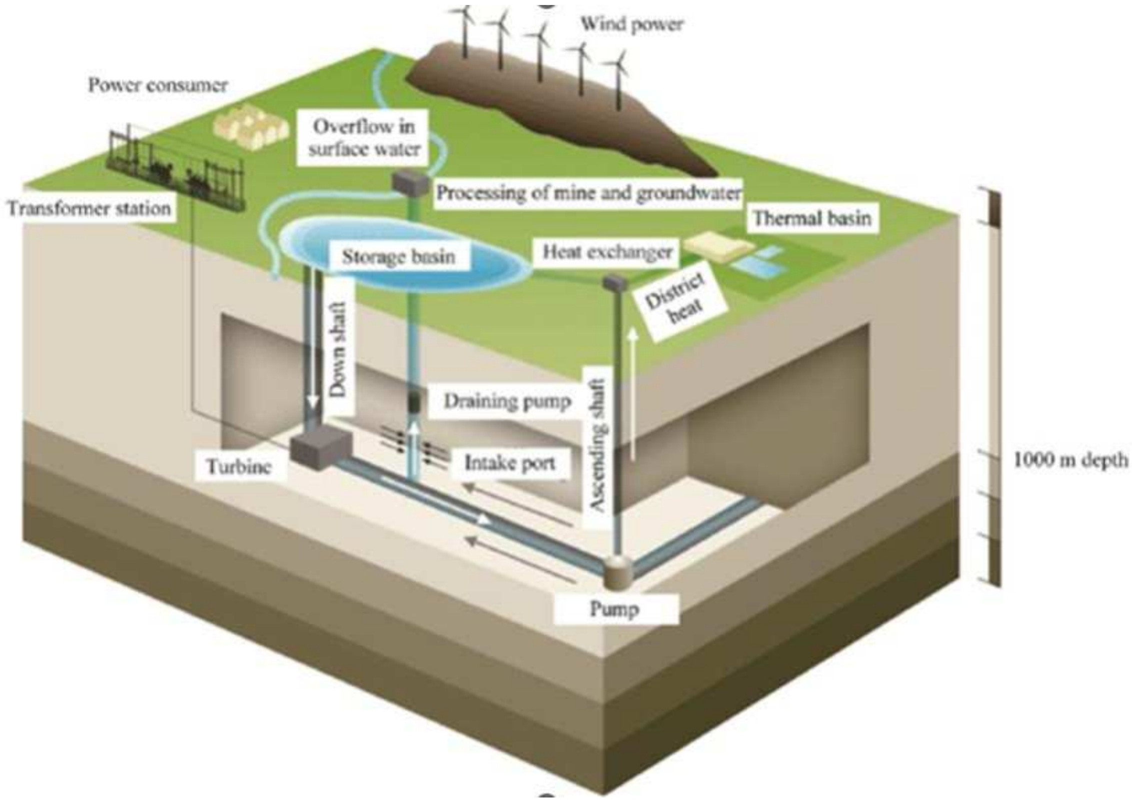
The researchers concluded that using abandoned coal mine goaves for pumped hydro facilities is technically feasible; however, they warned that locations with low pH value should be avoided, as acid goaf water could corrode the plant components, and release metal ions, or heavy metals, thus damaging the underground structures and polluting the surrounding water bodies. "Necessary purification treatments are very important to water safety," they said.

3. Ruhr area, Alvarado

In the Ruhr area, Alvarado et al. (2016) presented a project of the possible construction of underground pumped storage power plant in Prosper-Haniel mine in Bottrop (North-Rhine Wesphalia), using existing coal mine infrastructure[53]. After half a century of service, the Prosper-Haniel hard coal mine in the north-west of the Germany is due to be shut down in 2018[54]. Repurposing of the coal mine has been studied for conversion into a site for storing and generating electricity using the principles of pumped underground storage hydro (PUSH) with the principal objective of providing increased energy storage capacity and grid reliability in the region.

The mine has a horizontal underground roadway that extends for approximately 25 km. The roadway depth is 1.2 km, and the potential water storage capacity is 1 million m^3. Researchers from several German universities are working with private engineering firms and the government on the project and have been running feasibility studies on the site since 2012. If the project is a success, more mines like this could be adapted. The 600-metre-deep (1,969-foot) mine provides something the area doesn't have naturally – elevation. The flow of water powers the turbines and generates electricity, with water pumped back up again during periods of low demand.

Figure 12: Scheme of the pumped storage hydropower plant in the Prosper-Haniel mine in Bottrop, Germany



Source: https://www.researchgate.net/figure/Scheme-of-the-pumped-storage-hydropower-plant-in-the-Prosper-Haniel-mine-in-Bottrop_fig3_338758975

4. Upper Harz, Germany

Germany also plans to build a fully underground PSH plant in Upper Harz, where an abandoned metal mine with a roadway of diameter 3.5 m and depth of 760 m is used as an underground reservoir. The reservoir capacity is estimated to be 2,50,000 m^3, and the installed capacity is 100 MW[55].

5. Asturian coal mine, Spain

The mine water inrush in the Asturian coal mine in Spain is exploited as the water source to build a semi-underground PSH plant[56].

6. Kentucky, USA

Recently in the USA, Rivian announced a renewable power project in collaboration with BrightNight and The Nature Conservancy. Located on the Starfire Mine in Eastern Kentucky, it will be the largest conversion of a former coal mining site to solar project in the United

Figure 13: General view of the surface area for project development

Source: https://stories.rivian.com/former-coal-mine-to-solar-

States bringing reliable energy to local communities and enabling widespread electrification that is powered by responsible clean energy. The first phase of the project will power more than 450 million miles of driving for Rivian vehicles every year. Rivian worked closely with The Nature Conservancy to co-develop "Power with Purpose", an open-source guide that considers full impact by weighing conservation, climate and community as key decision factors for project selection.

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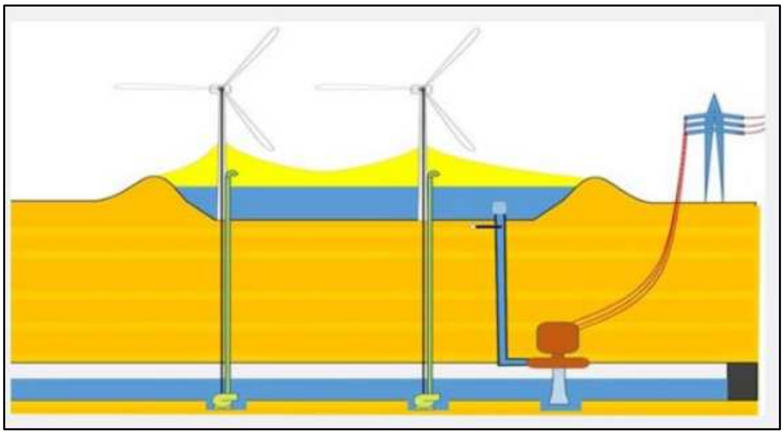
7. Abandoned Mine Lands (AML)

The use of mine voids for pumped storage hydro (PSH) has been studied in the US (other similar studies have been undertaken in Austria) with Abandoned Mine Lands (AML)have been studied extensively in many states, including Indiana[57,58,59,60,61]. Pumped Storage Hydro (PSH) is geographically limited but can expand greatly if abandoned subsurface coal mines are leveraged for the lower reservoir (PUSH). Such lands are already permitted, generally less desirable for other purposes, and found in regions eager for job creation. Water can be raised from the lower reservoir using electric pumps as part of energy arbitrage but does not exclude pumping utilizing other energy sources such as HWT.

Hydraulic technology is quite mature with products in the mining and oil and gas industries. HWT components last longer and are significantly less massive than conventional electric wind turbines, are lower in specific cost and can start-up at lower wind speeds. Lightweight HWT pumps mounted on tall masts take maximum advantage of the moderate wind resources generally found around Midwest mine lands. Construction work is straightforward, including the formation of a surface lake of 250 acres to a depth of 33 feet. The upper reservoir is lined with bentonite clay, and the shorelines protected with rip-rap and filled from local subsurface water. Many communities already use subsurface reservoirs from coal mining for drinking water - this being fairly common in Kentucky[62,63,64,65,66,67,68].

Although some abandoned mines have left environmental problems without funding for remediation, the concept includes repurposing of these lands using the skills of coal miners who have lost work due to slackening global demand, for example, ex-miners can be employed in remedial mine works, where seepage underground is excessive. In such cases, the walls in room and pillar mines can be coated with spray-applied shotcrete to eliminate

Figure 14: Conceptual design for integration of Hydraulic Wind Turbines



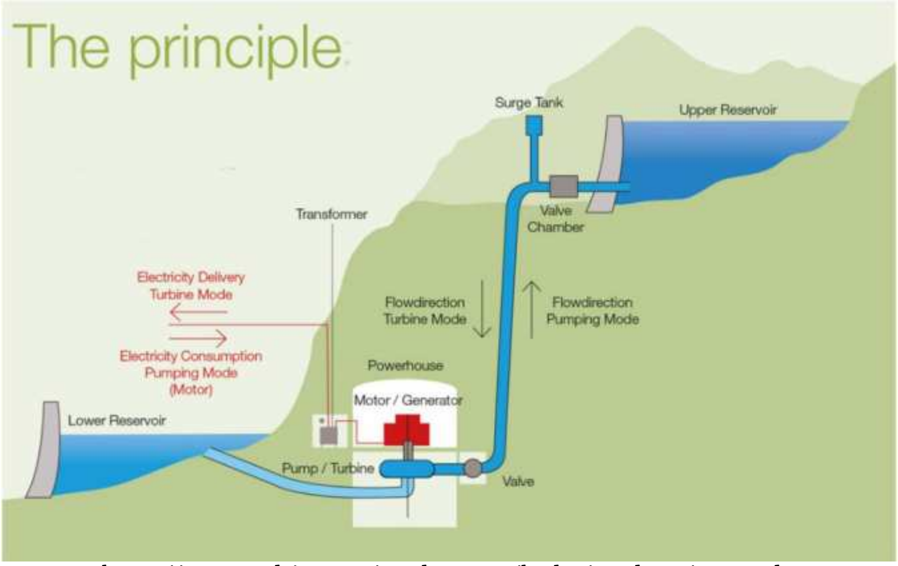
Source: https://juniperpublishers.com/imst/IMST.MS.ID.555563.php

erosion from water flows and changes in hydrostatic pressures during operation. Similarly, French drains (lowered culverts) in the underlying rock can be used at the

5.3. Working principle of technology

Pumped storage offers the predominant technology available for large-scale electrical energy storage solutions. During periods of low power demand, surplus energy from the grid is harnessed to transfer water from a lower reservoir to an upper reservoir, effectively converting electrical energy into potential energy for storage. Conversely, when power demand peaks, water from the upper reservoir is released, driving hydraulic turbines that convert this stored potential energy back into electricity for the grid. These pumped storage power plants employ water as the conveyance medium, utilizing their own turbines and pumps to facilitate this energy transformation.

Figure 15: Conceptual principal arrangement of Pumped Storage Hydropower



Source: https://www.andritz.com/products-en/hydro/products/pumped-storage

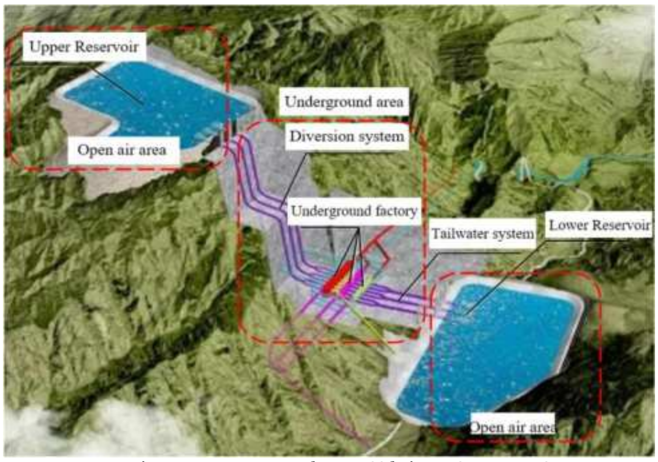
Furthermore, abandoned mines offer a real and cost-effective opportunity for converting subterranean spaces into energy storage reservoirs by implementing a water conveyance system to establish a comprehensive pumped storage system. The same principles apply to deep pumped storage (PUSH) with the difference the lower reservoir is located at a much greater depth.

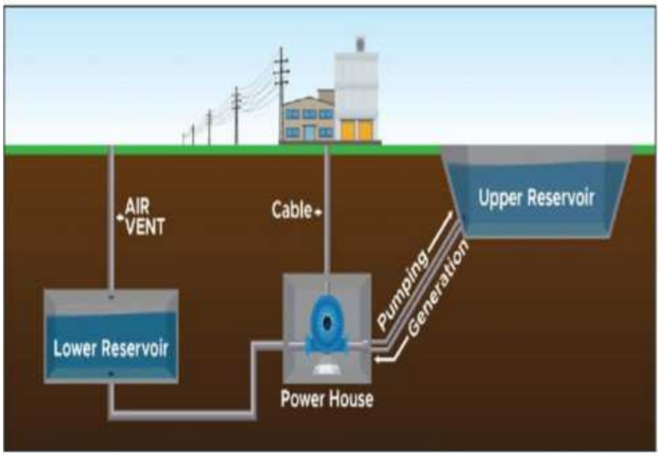
This innovative approach can be further expanded into a complementary distributed smart energy system (with air vent to Lower underground reservoir). The development of this technology holds the potential to reinvigorate abandoned mine sites, transforming them into valuable assets. This, in turn, can spark the growth of the clean energy sector and associated industrial chains, catalyzing the revitalization of cities facing resource depletion.

The repurposing of sites for PSH and PUSH is complex, and project specifics will vary greatly depending on the site's characteristics and local requirements. Collaboration with relevant stakeholders, including local communities, environmental organizations, and regulatory bodies, is crucial for a successful repurposing project. Additionally, advancements in technology and changes in regulations may impact global practices for PSH and PUSH repurposing over time.

Repurposing surface or underground coal mines into PSH facilities involves transforming abandoned or still active mine sites into energy storage systems. The primary benefit of repurposing surface works is to take advantage of the existing topographical features and infrastructure while deep open pit excavations can serve as natural lower reservoirs. Where there are underground coal mines these can provide underground chambers suitable for housing the pump-turbines as well as acting as the lower reservoir.

Figure 16: Pumped Storage scheme with open (source: Energies 2023) and underground (source: ESA 2019) lower reservoir





Source: Energies 2023, 16, 314. https://doi.org/10.3390/en16010314 in www.mdpi.com/journal/energies

This repurposing approach offers an effective means of energy storage and grid stabilization, particularly in regions with intermittent renewable energy sources or fluctuating electricity demand. For example, the Dinorwig UK PSH project uses two of the 250 MW for frequency stabilization and the remaining units to meet peak demand. Completed in the early 1980's the scheme paid for itself in 10 years.

Figure 17: Dinorwig Machine Hall during M&E installations

Source: TheCivilEngineer.orghttps://www.thecivilengineer.org › news › one-of-the-l...

Moreover, when designing pumped storage schemes, it is worth considering the following generalized criteria that can help determine its viability although, it is important to keep in mind that these generalized criteria are a guideline only and may vary depending on the specific site conditions.

1. The minimum head (hydraulic head) required for a viable pumped storage hydropower project typically ranges from 100 meters (approximately 328 feet) to 300 meters (approximately 984 feet), although there are variations based on specific project conditions and objectives.

2. A higher head allows for greater potential energy storage, making them more suitable for managing peak electricity demand. In addition, projects with a higher head often have greater energy conversion efficiency since they generate more power for the same water flow resulting in a more cost-effective and energy-efficient operation.
3. A general guideline for Length/Head (L/H) ratios in PSH projects is typically between 2:1 to 10:1, but it can go beyond this range depending on the characteristics of individual project.
4. PSH projects with higher hydraulic heads (vertical distance between upper and lower reservoirs) can have shorter penstocks and tunnels, resulting in L/H ratios at the lower end of the range. This is often the case in mountainous or hilly regions.
5. For projects with lower hydraulic heads, the length of the penstock and tunnels may need to be extended to maintain efficiency. This is more common in flatter or less elevated terrains and leads to higher L/H ratios.
6. Projects with less than six hours energy storage are generally not considered on the basis that the minimum energy storage capacity requirement is likely to be six hours given the period of reduced demand that coincides with mainland rooftop solar and solar PV capacity.

5.4. Conditions determining suitability of technology

The specific conditions that are required for the technology are as follows.

5.4.1. General

Any conventional pumped storage project consists of the following parts: an upper reservoir, waterways, reversible (pump/generator) turbines or separated units of peltons and pumps, and a lower reservoir. Pumped storage hydropower (PSH or PUSH) plant projects can utilize abandoned mines whether in the form of open pits or deep shaft mines. They can convert intermittent electricity from RE sources into useful energy that is then available on an as required basis.

- **Selection of Suitable Sites:** The first step would be identification and selection of coal mines that have the potential for repurposing for either PSH or PUSH projects. These mines should meet certain criteria, such as having a suitable topographical layout, access to water sources, and proximity to the electricity grid.
- **Upper and Lower Reservoirs:** In the case of deep open pit mines, existing open pit can serve as the lower reservoir with a new surface upper reservoir or water storage facility constructed near the coal mine site. This upper reservoir is essential for storing water used in the PSH system and storage capacity depends on the proposed generating capacity. In underground mines surface upper and underground lower reservoirs are required for PUSH. The extent of works necessary to develop the lower reservoir from existing mine shafts and the underground powerhouse complex will depend on the state and condition of the underground works and the degree of rehabilitation required.
- **Pump-Turbine Installation:** Within or near the mine pump-turbines are installed. These machines serve a dual purpose: they can act as pumps to move water from the lower

reservoir to the upper reservoir when surplus electricity is available and reverse their operation to work as turbines for power generation when demand is high.

- **Water Circulation:** During periods of excess electricity supply or low demand, typically when renewable energy sources like wind and solar are producing surplus power, low-cost excess electricity is used to power the pumps. The pumps move water from the lower reservoir to the upper reservoir, effectively storing the energy as gravitational potential energy.
- **Generation of Electricity:** When electricity demand is high or when renewable energy supply is low, water is released from the upper reservoir back into the lower reservoir. As the water flows downhill, it passes through the same pump-turbines, which now operate as turbines to generate electricity by converting the kinetic energy of the flowing water into electrical energy.
- **Grid Balancing:** The generated electricity is supplied to the grid to meet peak demand or stabilize the grid during fluctuations in power supply and demand, or a combination of both.
- **Repeat Cycle:** The process of pumping water from the lower reservoir to the upper reservoir during periods of low electricity demand and releasing it to generate electricity during high demand occurs on a cyclical basis several times daily to help maintain grid stability.

5.4.2. Pumped Storage Options

Based on the above discussion, there are two options available when repurposing abandoned mines for Pumped Storage Projects –

- PSH that uses a deep open pit mine as lower reservoir and, where possible an existing open pit mine as the upper reservoir.
- PUSH that uses underground mine shafts and mine workings as the lower reservoir.

In both the above-mentioned options, the following conditions are necessary for repurposing of the mines for pumped storage:

- The elevation difference between the upper and lower reservoirs using open mine pits should remain relatively high to ensure efficient operation of the hydraulic turbines. This is less of a problem for PUSH projects.
- The effective storage capacity (volume of the reservoir between maximum and minimum water levels) of the two reservoirs should be equal.

5.4.2.1. Pumped Storage Project using open pit as lower reservoir (PSH)

Using a deep open pit mine as a lower reservoir is a practical and cost-effective solution but a number of factors require close examination for their use as permanent structures. Based on a comprehensive evaluation of the ground conditions and the identified main hazards, where the risk levels are unacceptably high a risk assessment is normally an imperative to consider mitigation measures that reduce risk levels to as low as reasonably practical (ALARP) for operational purposes.

The following are some of the main hazards:

a. A shift to use of the mine as a lower reservoir for a PSH scheme is a major functional change. The design life is significantly longer and combined with the use of the lower part of the mine as a reservoir requires a general reassessment of the parameters used for design purposes.

b. Open cast mines can reach depths of 300m+ and typically will be benched for both operational and safety reasons. The overall stability of the slopes is managed safely during the lifetime of the mine. Once abandoned in the long-term weathering processes will result in a progressive loosening and potentially unstable slopes depending on the local rock mass characteristics.

c. The crest line of open pit mines is typically in poor rock due to the unloading and weathering processes. Depending on rock mass quality there may be the potential for circular slips, especially during monsoon conditions, and suitable control measures and/or remedial works implemented to manage the hazard.

d. There will be no changes in loading condition for slopes above the reservoir TWL. A detailed assessment of the rock mass quality and potential for kinematic block failures will be required above this elevation to determine the level of risk and if remedial works are required. For example, in the case of the Kidstone mine (Queensland, Australia) ensuring the long-term performance of the mine slopes involved reinforcing the bench faces with cable anchors.

e. The slopes forming the lower reservoir will require a thorough investigation of the geological and geotechnical conditions. A general recharge of the groundwater table increases the potential for slopes instability due to saturation. The changes in hydrostatic pressures due to fluctuations in water levels on a daily basis can negatively affect the slopes Factors of Safety (FOS).

f. Groundwater exchange and losses due to recharge will influence the PSH efficiency and will bring environmental impacts[69]. A key concern is recharging of the surrounding rock masses with water during operation can influence the efficiency of the pumps and turbines if the losses affect the head difference between the lower and upper reservoirs. An impermeable reservoir lining would generally be the preferred option.

g. Schemes for impervious reservoirs may include the following:

   i. The bottom and slope surfaces of the open pit are clean and flat.

   ii. A certain thickness of homogeneous clay is laid evenly at the bottom of the open pit, and a geomembrane with high breaking strength, tensile strength, and elongation is selected to cover the clay.

   iii. Concrete is used to reinforce the jointed or highly weathered rock masses on the slope surfaces.

   iv. Asphaltic concrete linings that provide an impervious membrane - as used for example on the Turlogh Hill PSH in Ireland.

h. There may be some residual settlement of the lower reservoir and foundations due to changes in hydrostatic pressures, but this is minimized and limited if the reservoir is lined with an impermeable membrane.

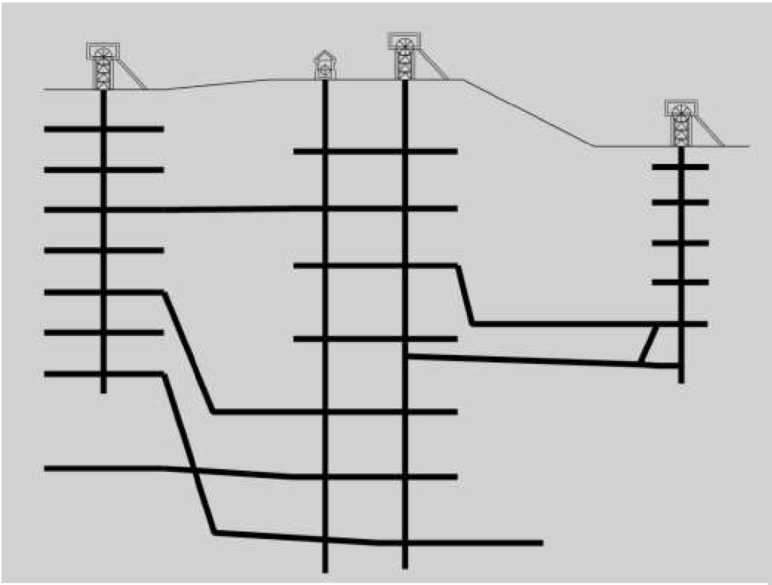
Generally, the selection of methods for assessing slope stability will involve standard software packages that are tried and proven in practice, e.g., Rocscience (Swedge, Phase II / RS II). In addition, there are useful approaches for looking at the impact of rock slope failures and whether they are likely to impact the lower reservoir[70].

5.4.2.2. Pumped Storage Project using abandoned mine shaft as lower reservoir (PUSH)

Repurposing deep underground coal mines for pumped storage[71] are being considered in several countries but there are no known examples of projects either under construction or completed. Where the site conditions make this feasible it remains an option and one that requires further investigation to establish and define the requirements for a successful conversion of the underground excavations from mining to civil purposes.

The required criteria for deep pumped storage are summarized in the "General" section above; but critical for the lower reservoir is the required volume of storage and the long-term stability of the underground works during operation. In terms of the mining, the challenges of employing abandoned or disused mines as a lower reservoir are multifaceted and often the records may not be complete either in terms of the extent of mine development or with respect to the support systems, their design and the current condition due to either a lack of or poor maintenance.

Figure 18: Typical scheme of shafts and tunnels network in coal mines



Source: Austrian Standards Institute (2013) "ONR 24810: Technical protection against rockfall – Terms and definitions, effects of actions, design, monitoring and maintenance." Austrian Standards Institute, Vienna Austria (in German), www.a-plus.at

The factors affecting the current state of the mine ground conditions in the post-mining period include the following:

a. Weathering – typically weaker beds such as shales and mudstone will exhibit a loss of strength due to unloading and pore pressure changes.

b. Dissolution – typically occurring where carbonates or evaporates are present within the prevailing stratigraphic sequence of mine elevations.

c. Pore pressure changes (hydration) – more specifically these will affect clay rich rocks leading to a gradual and progressive degradation of the mudstone, siltstones, and some shales.

d. Swelling – where water can gain access to rocks with micaceous clay minerals swelling pressures can develop with time, and this includes coal deposits.

e. Slaking – where mines are not flooded then both swelling and pore pressure changes enhance the degradation of the rocks surrounding the mine openings.

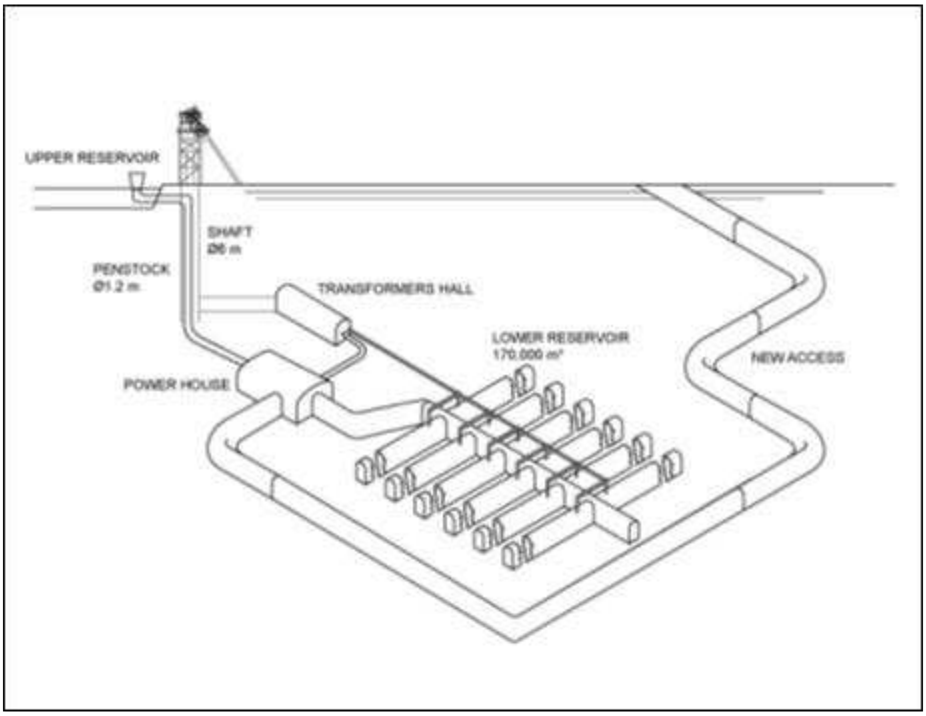
f. Deformations in the zone of disturbance – these may relate to structurally induced movements along faults or shear zones or possible to gas migrations.

Most of the processes described above are time-dependent and occur over considerable time. Existing support systems can limit deformations for a given period but load transfer due to creep combined with the effects of corrosion of the support elements will reduce system effectiveness. Eventual failure of the support systems leads to either progressive closure or complete collapse of sections of the mine.

These processes also will occur regardless of the use of the mine as a lower reservoir for PSH. Once operational and the reservoir filled, the increase in both hydrostatic pressures (relating to kinematic block stability) and pore pressures in the surrounding rocks (depending on porosity) may continue to promote degradation of the weaker materials at an enhanced rate if left unsupported. The concern is that this will impact the storage capacity of the lower reservoir.

When considering the stability of the mine openings, and in particular, the factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important. This demands a good understanding of the project geology, including the stratigraphy, the

Figure 19: Schematic diagram of a Pumped Storage project with mine shafts



Source: Austrian Standards Institute (2013) "ONR 24810: Technical protection against rockfall – Terms and definitions, effects of actions, design, monitoring and maintenance." Austrian Standards Institute, Vienna Austria (in German), www.a-plus.at

structural geology (faults, shear zones, bedding, and jointing) and both the intact and rock mass physical properties. In the case of deep coal mine excavations, use can be of available in-house records including the mapped geology, laboratory testing was undertaken and monitoring was done to determine the rock mass physical properties. It is now the standard practice for major underground works, including pumped storage projects to prepare a Geotechnical Baseline Report (GBR) based on site investigations. Full use should be made of existing data when preparing a GBR and mine inspections employed GBR to verify information and better understand the following:

a. The principal failure mechanisms that have been encountered during mine operation.
b. The effectiveness of the installed support measures, particularly in the older mine excavation.
c. The in-situ stress regime prevailing at the project site (i.e., the ratio of horizontal to vertical stresses).
d. The rate of degradation of the exposed weak beds such as coal, shale, siltstones, and mudstones, particularly in the older sections of the mine.
e. Using these studies, estimate the excavation volume losses that have occurred in the various sections of the mine and particularly those showing signs of distress.
f. The groundwater regime and the ability of the rock mass to limit leakage from the reservoir.

In practical terms, most deep coal mines usually are in relatively flat-lying coal sequences and typically the optimum support system has been to install crown and sometimes invert support. This takes the form of rock bolts designed to create a deep beam effect such that the deformations in the crown are tightly controlled to limit the extent of any zone of disturbance. This principle makes full use of the strength and stiffness of the stronger layers forming the crown and invert, particularly the sandstone layers. Several mine manuals are available that detail the design of support systems using this approach[72,73,74,75]

Systematic roof support of the stiffer layers ensures that elastic behavior controls mine-stability. Strength-stress ratios for the weaker layers such as coal, mudstone, siltstone, and shales given the applied vertical loads are likely to be close to or well below (especially if coal is as weak as 2MPa) and therefore without the confinement of much stiffer layers would be subject to on-going elasto-plastic deformations. As far as mine stability is concerned, this is a key problem when commissioning a lower reservoir.

The rock mass is in a drained condition prior to watering up and there may be several sections of mine openings at or close to limiting equilibrium, i.e., close to failure. As the lower reservoir is filled, the increase in hydrostatic pressures can lead to tunnel failures due to a reduction in the rock mass effective shear strength. This effect is also relevant with respect to the increase in pore pressures and therefore progressive degradation of the weaker rock units due to slaking.

The process that is required to satisfy the safe operation of the lower mine as a storage facility therefore requires the following:

a. A full understanding of the ground conditions within the zone of influence of the lower reservoir when in operation.
b. An assessment of the current state of the openings to determine what additional support requirements may be needed to prevent loss of storage capacity.
c. An assessment of the impact of changes of hydrostatic pressures on opening stability on a cyclical basis during the lifetime of the project.

d. Assuming surface degradation (slaking) and some loss of storage capacity due to localized shear failures of the rock mass, estimate the additional storage capacity required to maintain system operational effectiveness.

e. Determine what measures are required to limit the lower reservoir volume capacity, i.e., close off redundant workings.

f. Estimate reservoir losses due to leakage into the rock mass either generally or in relation to specific features such as faults.

5.4.3. Geological Risks

Associated geotechnical risks could involve the following:

a. Surface settlements from underground mine workings, i.e., the risk of trough subsidence is a consideration depending on the scope of the works and the operational regime.

b. For all underground mines there is the possibility of sinkholes could be a major issue.

c. A major concern for coal mines is the presence of methane gas and acid mine drainage, both of which require investigation and the impact on the future planning of the project.

d. The prevailing condition in terms of groundwater levels and the possibility of sudden flooding could impact the repurposing option.

e. Most mine water is corrosive, which can easily aggravate the cavitation effect of the super-high head water pump hydraulic turbine. Hence, it is an inevitable requirement for the water pump hydraulic turbine of the abandoned-mine pumped storage power station to develop the key technology for corrosion–sediment wear–cavitation coordinated control technology of the water pump hydraulic turbine[76,77].

In the above context, evaluation of the hazards and associated risks is critical to the selection, planning and implementation of underground pumped hydroelectric energy storage (UPHES) for repurposing. This should reflect current practices for managing risks in underground works and the International Tunnelling Association has recently updated its guidance on this. This approach will look at all the key indicators governing the successful use of deep mines and a particular aim will be the planning of on-site testing to close out specific risks in mines selected as optimum for repurposing.

In China, others have begun to establish methodologies for evaluating site selection. The following are examples of their approaches:

a. In the Henan Province (Three coal mines located in Yima (M1), Jiaozuo (M2), and Hebi (M3) the overall UPHES potential of coal mines were attempted by a two-step site selection concept, including a screening assessment followed by a comprehensive assessment[78],. The screening indicators in the screening assessment comprise geological features, mine water disasters, and minimum installed capacity. In this process, the underground space volume of suitable coal mines is evaluated followed by an estimation of the potential for UPHES.

Figure 20: Location of three potential coal mines for UPHES in Henan

Source: A Two-Step Site Selection Concept for Underground Pumped Hydroelectric Energy Storage and Potential Estimation of Coal Mines in Henan Province Qianjun Chen, Zhengmeng Hou, Xuning Wu, Shengyou Zhang, Wei Sun, Yanli Fang, Lin Wu, Liangchao Huang and Tian Zhang in Energies 2023, 16, 4811. https//doi.org/10.3390/en16124811

a. Tao et al. proposed a hybrid multi-criteria decision-making framework for UPHES in abandoned coal mines that employs a framework and a traditional one-step assessment. This one-step assessment may weaken the impacts of geological and hydrogeological conditions, both of which are important for PSH operation[79].

b. Yong et al. introduced a two-stage fuzzy evaluation model for site selection, which included an initial veto that excludes candidate sites failing to meet the requirements of certain restrictive indicators. For example, permeability coefficients and horizontal distance were determined as two restrictive indicators with respect to the properties of coal mine goaves. In general, the drifts and shafts of old coal mines are more suitable for retrofitting into reservoirs making these restrictive indicators of low significance[80].

5.5. Potential for symbiosis with other repurposing options

Table 11: Potential symbiosis with Pumped storage hydropower

Repurposing options	Degree to which options can be combined with PSH
Thermal energy storage	Combining thermal energy storage with PSH can increase the efficiency and flexibility of the system. Heat can be stored during low energy requirement, and during high electricity demand, the stored heat can be used to increase the

Repurposing options	Degree to which options can be combined with PSH
	efficiency of PSH by preheating the water before it enters the turbines. The integration allows better manage the fluctuating energy requirements.
Wind Energy on Mining Land	The idea is to utilize the surplus wind power during nighttime to pump water from lower reservoir to upper reservoir and during daytime when the power demand is high produce hydropower to improve the power system[81].
PV on Mining Land	Solar PV can be used to pump water during off-pick time and can help in releasing during peak time through Pico hydro turbine to ensure stability in energy flow. Solar PV can be a potential substitute to the conventional diesel-based hydro pumping system[82]. The main storage technology used for both stand-alone and grid-connected PV systems is based on batteries, but other solutions like water/seawater pumped storage can be considered. From the life cycle assessment used to compare Energy Storage System (ESS) of different nature, it emerged that PHS have the highest Energy Storage On Energy Invested (ESOI) index of 210. ESOI is the total amount of energy stored over the lifetime of a storage technology unit, divided by the amount of energy used in producing that unit, i.e. kWh/kWh. Among the batteries Li-ion has the highest ESOI, that is 10, evidently much lower than PHS[83].
Ecotourism	Integrating ecotourism and PSH can bring sustainable energy practice while preserving nature. The reservoirs add picturesque views, the visitors can visit the areas and understand how the system works whilst enjoying hiking and observing the wildlife.
Water Storage & Flood Protection	Pit lakes act as flood protection measures for nearby water bodies. When any other water body near the pit lake overflows, that water gets redirected to the pit lake. Thus, pit lakes can be used as one of the reservoirs for the PSH to generate electricity.
Horticulture	Horticulture can be set up near the reservoirs, and the water can be utilized for irrigation purposes. And electricity requirement can be fulfilled with power generated by the PSH plant.

Source: PwC Analysis

Table 12: Potential symbiosis with Pumped underground storage hydropower

Repurposing options	Degree to which options can be combined with PUSH
Wind Energy on Mining Land	By utilizing wind energy with PUSH, the excess wind energy can be used to pump the water during low demand periods, and when the power demand increases, the stored energy is used to generate electricity through hydropower.
Water Storage & Flood Protection	Pit lakes act as flood protection measures for nearby water bodies. When any other water body near the pit lake overflows, that water get redirected to the pit lake. Thus, pit lakes can be used as the upper reservoir to generate electricity.
PV on Mining Land	By utilizing solar energy with PUSH, the excess wind energy can be used to pump the water during low demand period, and when the power demand increases, the stored energy is used to generate electricity through hydropower.
Geothermal Energy	Geothermal energy provides a continuous power source, and PUSH can store excess energy during low power demand. During increased power demand, water is released from the upper reservoir to the lower one generating electricity to meet the need. The integration provides an eco-friendly energy generation option.

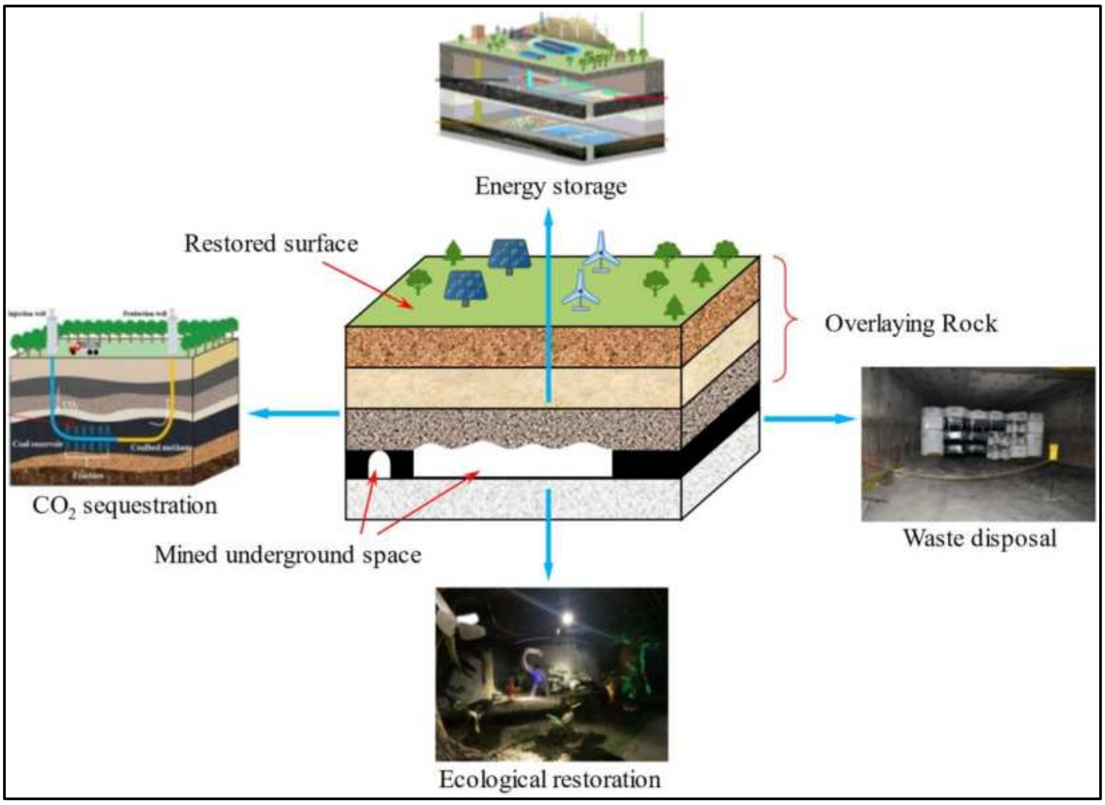
Source: PwC Analysis

Numerous technological choices are at the disposal for repurposing, including solar photovoltaics, concentrated solar energy, biomass, battery energy storage systems (BESS), offshore wind, synchronous condenser (SynCON)[84] (used for grid stabilization)[85], and more. Among these, the selection of repurposing options demands thoughtful assessment of a variety of factors, including the availability of resources, the power system's requirements, and the renewable energy targets specific to each country. For example, in the case of India, the widespread integration of variable renewable energy sources, fueled by India's ambitious renewable energy goals and the affordability of solar photovoltaic technologies, would necessitate approximately 27 gigawatts (GW) of battery energy storage systems (BESS) and substantial ancillary services provided by SynCON by 2030[86]. Therefore, the primary focus revolves around these three repurposing alternatives, namely, solar, BESS, and SynCON.

However, the old coal mines contain a significant amount of underground space that is available and accessible, such as hundreds of meters deep shafts, extensive drift networks, and ample goaves. Generally, the utilization modes of underground space in old mines can be categorized into four aspects: energy storage, waste disposal, ecological restoration, and CO_2 sequestration[87].

Redeveloping old mines for underground energy storage not only offers a second life to otherwise unused assets but also can support the promotion of local renewable energy projects[88]. Solar and wind power are intermittent and subject to seasonal and weather-dependent variation. Therefore, the power grid needs to be equipped with energy storage facilities to balance supply and demand. The growing integration of renewable energy into the power grid would increase the demand for energy storage facilities, especially large-scale energy storage. The abundant underground space contained in the old mines has the potential to provide a guarantee for large-scale underground energy storage. These repurposed initiatives can also serve as an opportunity to engage the private sector in a public-private partnership (PPP) arrangement, which, in turn, can lead to decreased capital expenditure (CAPEX) needs for the repurposing effort, reduced debt burden, and the generation of an additional revenue source for the public utility. The PPP model helps to infuse money in the system, where the ownership stays with the government and the capital and risk of the engagements is borne by the private player. This is to ensure that the engagement is done effectively through the expertise of the private players whilst the ownership remains with the government.

Figure 21: The four utilization modes of mined underground space in old mines



Source: https://www.mdpi.com/1996-1073/16/12/4811#B40-energies-16-04811

5.6. Potential environmental impact locally and GHG emission reduction potential

Pumped storage hydropower is considered to be the greenest renewable energy technology suitable for large-scale energy storage. Researchers from National Renewable Energy Laboratory suggested that closed-loop PSH will have lower carbon footprint throughout its lifecycle, from construction to decommissioning, when compared to other renewable energy storage options like lithium-ion batteries[89].

As per a MIT Center for Energy and Environmental Policy Research study[90], the results showed that pumped hydro storage facilitates dispatched more low-carbon generations. Generation from both wind and solar increased significantly because of the availability of the pumped hydro storage and GHG emissions reduced significantly. In the that study it was reflected that, a 440 MW of capacity will lead to a 0.1 megaton reduction in GHGs[91].

5.7. Employment effects

Currently, many resource-dependent mining communities encounter significant challenges, including resource depletion, economic stagnation, and population decline. By fostering the expansion and repurposing of abandoned-mine pumped storage initiatives and facilitating a range of business activities such as the installation, operation, and maintenance of mining infrastructure, it offers a promising avenue to address various social issues, notably the re-employment of abandoned mine workers. The abandoned-mine pumped storage project has spurred the revitalization and transformation of underutilized coal mines, addressing the challenge of providing alternative employment opportunities for mining workers.

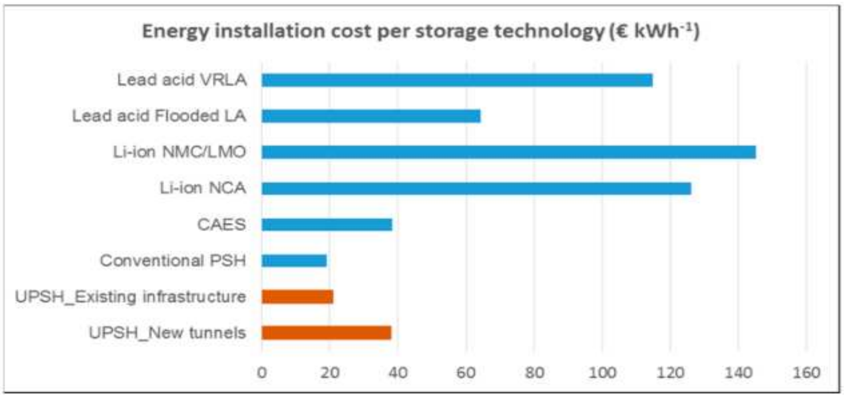
The employment opportunities created by pumped storage hydro projects can be significant depending on the mine status and necessity for repurposing. The initial phase of developing a pumped storage hydro project involves significant construction work which can support employment of a large number of workers, (of the order of 400 to 450 personnel) including engineers, construction workers, equipment operators, and support staff. Once the project is operational, there is a need for a skilled workforce to operate and maintain the facilities (about 40 to 50 workers). This includes technicians, engineers, electricians, and other specialists to ensure the smooth functioning of the hydroelectric plant and associated infrastructure. Besides these, to adhere to the environmental and ecological impact assessments and regulations specialists in these fields may be employed to monitor and mitigate environmental effects, as well as ensuring compliance with regulations. Furthermore, the pumped storage hydro initiatives require administrative and support personnel. These include project managers, administrative staff, human resources, and financial experts.

Therefore, the repurposed facility would continue to support local economies and the surrounding communities by creating employment opportunities and facilitating economic activities, ultimately contributing to their long-term well-being.

5.8. Economic feasibility analysis

The economic feasibility of Pumped Storage Hydropower (PSH) depends upon two key factors: the revenue generated from selling electricity and the expenses associated with producing energy. PSH technology primarily serves as a large-scale electrical energy storage solution. When evaluating the installation costs of various energy storage technologies (expressed in EUR per kWh), a comparison has been made with conventional Pumped Storage Hydro (PSH) plants. A conventional PSH plant consists of two water reservoirs located at the surface, both upper and lower reservoirs. In Figure 47 below, we observe the projected installation costs for several energy storage types by the year 2030, highlighting the cost-effectiveness of traditional Pumped Storage Hydro (EUR 19 per kWh), followed closely by Compressed Air Energy Storage (CAES) systems (EUR 38.26 per kWh). Electrochemical storage, such as lithium-ion, while pricier to install, boasts superior energy storage and release efficiency, expanding its potential applications. For UPSH plants utilizing existing infrastructure, the installation cost stands at EUR 20.90 per kWh, but when factoring in the excavation of new tunnels, the cost increases to EUR 38 per kWh. This comparison sheds light on the energy installation cost disparity between battery storage technologies and PSH.

Figure 22: Energy installation cost of battery storage technologies vs. PSH plants



LA: Lead-acid
LMO: Lithium manganese oxide
NCA: Nickel cobalt aluminium NMC: Nickel manganese cobalt
NCA: Nickel cobalt aluminium VRLA: Valve-regulated lead-acid

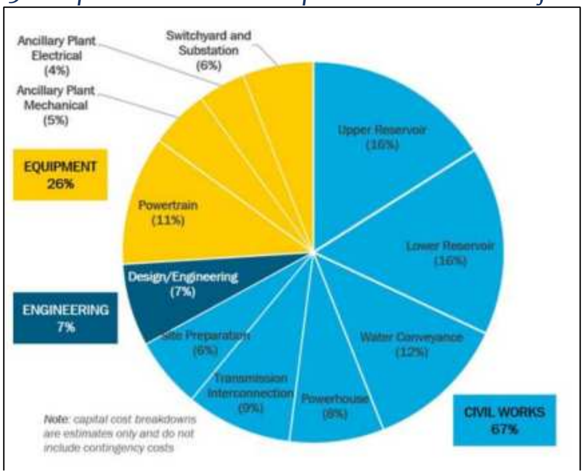
Source: Source: https://www.mdpi.com/2076-3417/10/11/3947

Furthermore, it is important to consider the economic benefits of a repurposed pumped storage hydropower projects in terms of the following:

1. Peak-load regulation and shifting of power grid
2. Saving of operation and construction costs
3. Re-employment of mining-related workers
4. New energy power storage level
5. Treatment cost of sewage in the mine
6. Emission reduction of hazardous gases
7. Environmental governance policy support
8. Surplus electrical energy of power grid.

The capital cost breakdown for the PSH project is shown in figure 48 and 49. The construction costs of the upper and lower reservoirs constitute 32% of the capital cost. Repurposing the existing abandoned coal mines as an upper or lower reservoir, or both, will definitely reduce the capital cost of the project. In every Pumped Storage Hydro (PSH) project, the necessity for two reservoirs is evident—one positioned at a higher elevation and another at a lower elevation. This significant difference in elevation is essential for power generation. Consequently, if either or both of the reservoirs already exist, the expenses

Figure 23: A representative total capital cost breakdown for a PSH



Source: Hydrowires, 2020, US Department of Energy: Pumped Storage Hydropower FAST Commissioning Technical Analysis related to excavation and the construction of embankments can be eliminated, resulting in substantial cost savings.

Additionally, the need for extra land to accommodate the reservoirs becomes unnecessary, leading to further cost reductions. Utilizing existing coal mine pits as potential reservoir presents an opportunity to save on the capital costs associated with PSH projects.. In India, the PSH cost per MW varies from 4 to 6 crore per MW. However, it's important to note that the cost can vary widely depending on the specific requirements of the project. As per CERC guidelines 2019-2024 the operation and maintenance expenses are 3.5% of the actual cost for the first year of operation, with an escalation of 4.77% per annum thereafter. Pumped hydro storage plants have a lifetime of more than 40 years. And considerably longer periodic refurbishment.

Figure 24: Typical PSH project time, cost, and risk breakdown

Category	Components	Cost	Component cost % of total project costs	Time duration	Risk	Component cost reduction potential	Component time reduction potential	Constraints	Cost drivers	Cost makeup
Civil works	Upper reservoir	High	16	Long	High	High	High	Location, volume, terrain, and geotechnical	Material type and volume	Labor and equipment
	Lower reservoir	High	16	Long	High	High	High	Location, volume, terrain, and geotechnical	Material type and volume	Labor and equipment
	Water conveyance	High	12	Long	High	High	High	Reservoir distance, terrain, geotechnical, and siting	Siting	Materials, labor, and equipment
	Transmission interconnection	Med	9	Long	Med	Med	Med	Routing and voltage	Length and voltage	Materials and equipment
	Site preparation	Low	6	Med	Med	Med	Low	Geotechnical and site layout	Site access and area	Labor and equipment
	Powerhouse	Med	8	Med	Med	Med	Med	Terrain, geotechnical, and siting	Siting	Materials, labor, and equipment
Equipment	Powertrain	Med	11	Med	Low	Low	Low	Procurement	Unit type and capacity	Procurement
	Switchyard and substation	Low	6	Med	Low	Low	Med	Geotechnical and site layout	Quantity and voltage	Materials, labor, and equipment
	Ancillary plant (mechanical)	Low	5	Short	Low	Low	Low	Site layout	Quantity and voltage	Procurement
	Ancillary plant (electrical)	Low	4	Short	Low	Low	Low	Site layout	Quantity and voltage	Procurement
Engineering	Design/ engineering	Low	7	Med	Low	Low	Low	Geotechnical and site layout	Siting and project size	Labor

Table notes:

1. Costs can vary depending upon location and site-specific characteristics.
2. Time, cost, and risk are greater for underground than aboveground projects (e.g., siting), subject to the economies of scale.
3. Very little manufacturing and installation risk is associated with major equipment suppliers.
4. Reservoir dam height and site conditions/terrain drive the cost of civil subcomponents.

Source: Information from Knight Piésold consulting in collaboration with ORNL, 2019.

5.9. Pros and cons

Some of the major pros and cons of the Pumped Storage Project repurposing option are as follows.

Table 13: Pros and Cons of PSP

Pros	Cons
Enhancing the RE portfolio of the state – Developing Pumped Storage Hydropower project on the	**Topographical Challenge:** The availability of suitable sites is restricted by topography and existing uses.

Pros	Cons
abandoned mines shall add to the overall RE portfolio of the state and contribute to the national RE targets.	Sites must feature a significant elevation difference between upper and lower reservoirs. Many projects may have been abandoned due to public opposition or lack of regulatory approval.
Meeting Peak energy demand and Grid Stability - The sustainable energy transition with renewables increases electricity generation volatility. Pumped storage hydropower (PSH) plants offer reliable, fast energy storage, outperforming other storage options. Retiring Thermal plants presents a chance to boost renewables, add energy storage, and repurpose coal mines into PSH for grid stability.	**Hydrological challenges**: The key challenge is finding suitable locations. Abandoned-mine pumped storage relies on water flow to function, so having sufficient underground water resources in the mine is essential. With coal mine underground reservoir technology, storing enough mine water is crucial for effective pumped storage.
Increased revenues - A range of stakeholders involved in developing Pumped Storage project (including energy organizations, local employees, new assembling and manufacturing plants and investors) can add to a states and municipality's tax stream.	**Technical challenges** - Converting an original mine into a pumped storage reservoir requires impermeable rock formations and walls. Existing mines have varying rock strata with different water content, hardness, and corrosion resistance. Safety considerations in the project necessitate assessing the existing rock formations and well support conditions, choosing a permanent support structure, and avoiding fractured zones in overlying rock due to mining. Additionally, open cast mines face slope stability challenges.
Revitalization of abandoned property - Utilizing available land and transmission infrastructure is possible. Repurposing abandoned mines for pumped storage power stations minimizes landscape disruption, optimizes underground space, reduces costs and construction time, and addresses the pressing need for peak-load regulation and energy storage in power grid development.	**Working environment**: Underground gas in some abandoned mines is a significant uncertainty for pumped storage. Evaluating gas concentration, underground roadway topology, and power generation equipment installation is essential.
Social Benefit - Repurposing maintains some workforce for future renewable energy or storage projects at the same site, helping mitigate potential job losses. The repurposed plant, like the original coal plant, sustains local economies and communities by creating jobs and supporting long-term economic well-being.	**Health Hazard:** For underground mines, the influence of ground and water depth and water-gas alternation has potential safety hazard on the human health.
Job Opportunity: The construction and operation of PSH plants offer new job opportunities in those regions that have been subject to recent major structural change caused by the end of coal production, enabling the country to further push and facilitate the Energy turnaround.	**General Technical for underground mines:** Preventing seepage, providing support, and reinforcing underground spaces in abandoned-mine pumped storage is a challenging aspect of repurposing these areas.
Cost Impact: Repurposing a coal mine site can reduce the initial investment needed for new renewable energy or pumped storage projects, lowering the cost of generated power. It may also involve using the existing substation, eliminating the need for extra transmission and interconnection expenses, further reducing overall power costs.	
Underground Pumped Storage Project - An underground pumped storage hydropower (UPSHP) plant in a mineshaft might be slightly costlier than a	

Pros	Cons
conventional one, largely influenced by the available head height. Nevertheless, the potential for numerous suitable sites in flat terrain makes UPSHPs an attractive option for the future energy transition.	
Economic development - For coal mines located in urban and semi-urban areas, repurposing manifests in multiple end uses, leading to economic diversification benefiting local economies.	

Source: PwC Analysis

5.10. Suitability for India

India faces significant vulnerability to the repercussions of climate change, particularly because a considerable portion of its population relies on climate-sensitive economic activities, such as agriculture. Furthermore, the nation hosts several major coastal cities that are under the looming threat of rising sea levels driven by climate change[92].

Historically, coal has played a pivotal role in fulfilling India's energy requirements, yet the advantages of retiring coal plants (Thermal power plants) prematurely could establish a source of funds for new renewable energy (RE) projects[93]. India is already observing a decline in tariffs for RE, particularly in solar power, leading to the rapid integration of RE-based energy generation into their power grids. Meanwhile, the costs associated with coal-based electricity generation remain elevated, rendering its dispatch economically less viable[94].

In a major diversification plan, Coal India Limited (CIL)[95] and its subsidiaries are planning to set up pump storage projects (PSP) on huge tracts of de-coaled (closed mines) lands at their disposal. Under PSH, all mines where coal has been extracted will be subject to a feasibility study to assess their suitability as reservoir sites with the intention that pump will lift the stored water from the lower reservoirs (either PSH or PUSH) to upper reservoir using solar energy for generation purpose.

Though PSPs are common abroad and in India, the development of PSPs with repurposing an abandoned coal mine is a novel concept for India. A consultant will be appointed by the coal ministry for further development of the concept. As open-cast coal mines are potential eyesores, left idle once the coal is extracted, the idea of using them for PSHP will resolve many practical challenges. One such case study has been applied to the Open Cast Project-4 (OCP-4) coal mine in Karimnagar district, Telangana, India[96]. The suitable storage technology integration with the solar system makes the system more reliable and efficient. There are various storage options present in market today. Despite these, the Pumped Storage Hydro-power Plant's (PSHP's) short start-up time, economic viability, sustainability, and scalability for large-scale Hybrid Renewable Energy Sources (HRES) make it an attractive option for HRES projects.

According to the NEP document, the projected All India peak electricity demand and electrical energy requirement as per 20th Electric Power Survey (EPS) Demand projections has been presented in Table below. Further, it includes the likely projected total installed capacity and their break-ups for conventional and renewables based on generation planning studies carried out under the purview of preparation of National Electricity Plan for the period of 2022-27[97].

The projection of total capacity addition is in line with the target of the country to achieve a non-fossil based installed capacity of around 500 GW by the year 2029-30.

Table 14: Projected power demand, energy and installed capacity in All India Power scenario

Description	Year	Peak Demand (GW)	Electricity Energy (BU)	Installed capacity (MW)	Conventional (MW)	Renewables (MW)	BESS (MW)
The All India power projection scenario	2026-27	277.2	1907.8	609,591	Coal:235,133 Gas:24,824 Nuclear: 13,080	Large Hydro: 52,446 Solar: 185,566 Wind:72,895 Small Hydro: 5200 Biomass: 13,000 PSP: 7446	8680
	2031-32	366.4	2473.8	900,422	Coal:259,643 Gas:24,824 Nuclear: 19,680	Large Hydro: 62,178 Solar: 364,566 Wind: 122,895 Small Hydro: 5450 Biomass: 15,500 PSP: 26,686	47,244

Source : https://cea.nic.in/wp-content/uploads/irp/2023/05/NEP_2022_32_FINAL_GAZETTE-1.pdf

NEP envisages that the share of non-fossil-based capacity is likely to increase to 57.4% by the end of 2026-27 and may likely to further increase to 68.4% by the end of 2031-32 from around 42.5% as on April'2023.

The average PLF of the total Installed coal capacity of 235.1 GW is likely to be about 58.4% in 2026-27 and that of 259.6 GW of coal-based capacity is likely to be about 58.7 % in 2031-32.

To meet the above demand, the pumped storage hydropower is an essential choice to cope with the peaking power and grid stability.

The Government of India on 12 November 2023 said more than 20 abandoned mines have been identified by state-owned CIL for evaluation and feasibility study for pump storage projects. The information was shared by Coal India Ltd (CIL) as a part of a diversification review meeting held by Coal Secretary Amrit Lal Meena. The Coal Ministry said in a statement that state-owned NLCIL has also taken up a feasibility study on pump storage projects. Further, "The business model like EPC and PPP may be finalized in consultation with stakeholders and such projects may be implemented in collaboration with various stakeholders, including state Governments, private players and research institutions"[98] .

The coal ministry is embarking on a plan to develop such projects in de-coaled coal mines, leveraging the economic advantages of a vast land bank and economic viability. The aim of the plan is to diversify towards alternative sources of energy. The Ministry of Coal is committed to promoting sustainable development and optimizing resource utilization. Such initiative will help in promoting sustainable development and reducing the carbon footprint of the coal sector. The Ministry is steadfast in ensuring efficient use of resources and maintaining a consistent power supply to the citizens.

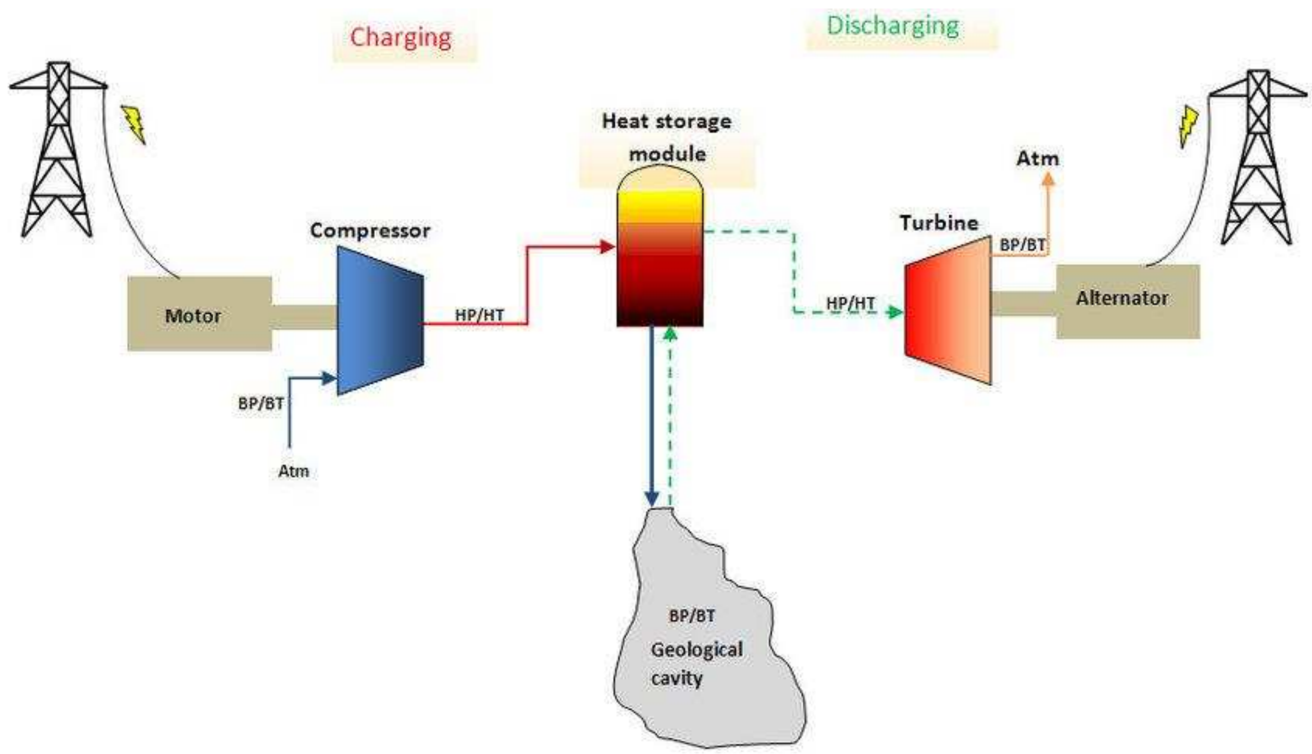
6. Compressed Air Storage - As Repurposing option

6.1. Introduction to repurposing option

CAES is a system used for storing vast amounts of energy. During the time of low power demand, the excess electricity is used to compress the air using electric compressors in which the energy is stored in the form of compressed air that is stored in a tank or a reservoir. The compressed air is released during the time of high-power demand to supply the electricity when needed. The compressed air is stored either in underground geological formations or in high pressure containers. Sometimes the heat generated during the compression phase is captured and used to reheat the air during expansion to make the process more efficient. There are different types of CAES systems that are currently under operation and development stage:

1. **Diabatic**: Most mature but average efficiency. Heat exchange is done, heat lost during compression.
2. **Adiabatic**: Heat during compression of air is harnessed and is used while expansion of air.
3. **Isothermal**: Increase and decrease in temperature is avoided during compression and expansion. This technology is under development.

Figure 25: Schematic diagram of adiabatic CAES



Source: Dynamic Behavior of a Sensible-heat based Thermal Energy Storage - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Scheme-of-adiabatic-compressed-air-energy-storage-A-CAES_fig2_274025595

CAES system is attractive as it can store large amount of energy for longer duration of time and ensures better integration of renewable energy source into the grid. CAES does not produce any direct greenhouse gas emission, has a lifespan which is generally exceeding 20 years. The system has a lower self-discharge rate as compared to chemical batteries and can be designed to match the specific energy storage needs. CAES does not use any scarce of energy sources as it needs only air.

Diabatic CAES is a mature technology and can be put up under level 9 of technology readiness. The diabatic and adiabatic CAES system/model is proven and ready for full commercial deployment whereas the isothermal system is still in development phase. An example of it includes CAES facility in Huntorf, Germany. It was the first commercial CAES facility in the world – and is still operating successfully today[99].

Some advantages of using underground coal mines to store compressed air are as follows:

1. Very high storage capacities of mines as CAES.
2. Relatively low cost since the excavations already exist and the geology of the site is relatively well recognized.
3. Many locations are directly connected to regional renewable energy sources or other energy sources.
4. Safe operation and protection against external factors since the underground system is separated from the surface and connected only by valves and pipes.
5. Large surface area available for the installation of the infrastructure.

6.2. Global best practices with examples

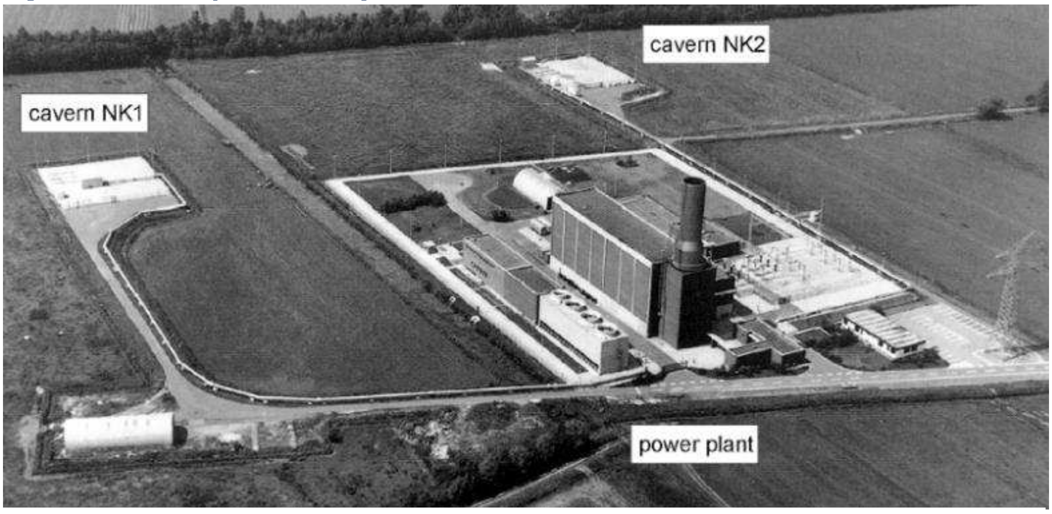
Mostly CAES storage has been set up in underground mines. The pressurized air is stored in caverns or storages constructed in an underground mine that can then be released when again there is a demand to generate electricity, by expansion of the air through an air turbine or gas turbine. The existence of large cavities and the reduced environmental impact make underground coal mines exceptionally suitable for CAES projects[100]. This technology has been adopted across the world for energy storage and some of the global best practices have been explained in the sections below.

The initial operational CAES facility, which was constructed in 1978, was the Huntorf plant in Germany with a capacity of 290 MW (upgraded to 321 MW in 2006). This facility utilized salt caverns that were solution-mined in a salt dome. The second CAES plant is located in McIntosh, Alabama, boasting a 110 MW capacity and a rated energy storage duration of 26 hours. The Huntorf plant is equipped with two salt caverns, each having a volume of about 310,000 m^3, situated at a depth of 600 meters, with daily pressure fluctuations between 43 and 70 bar. The McIntosh plant, on the other hand, has a total usable volume of approximately 5,38,000 m^3 within a salt cavern situated at a depth of about 450 meters, with allowable pressure ranging from 46 to 75 bar.

6.2.1. Huntorf

The Huntorf CAES plant, the world's first CAES facility, was completed in 1978 near Bremen, Germany. The 290 MW plant was designed and built by ABB to provide black-start services to nuclear units near the North Sea and to provide inexpensive peak power. It has operated successfully for almost three decades primarily as a peak shaving unit and to supplement other (hydroelectric) storage facilities on the system to fill the generation gap left by slow-responding medium-load coal plants[101].

Figure 26: Hunterof CAES Facility

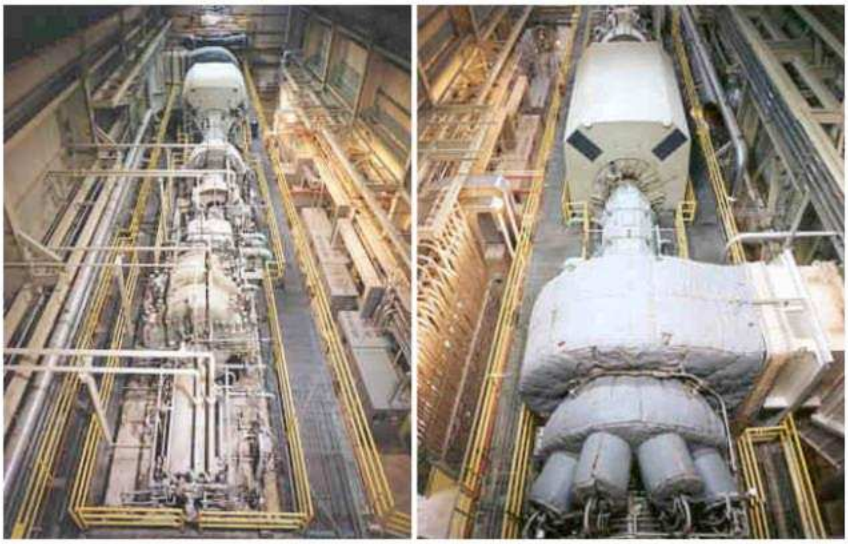


Source: https://acee.princeton.edu/wp-content/uploads/2016/10/SuccarWilliams_PEI_CAES_2008April8.pdf

6.2.2. McIntosh

The 110 MW McIntosh plant was built by the Alabama Electric Cooperative on the McIntosh salt dome in southwestern Alabama and has been in operation since 1991 (see Figure 51). It was designed for 26 hours of generation at full power and uses a single salt cavern (560,000 m^3) designed to operate between 45 and 74 bar. The project was developed by Dresser-Rand, but many of the operational aspects of the plant (inlet temperatures, pressures, etc.) are similar to those of the BBC design for the Huntorf plant. The facility does, however, include a heat recuperator that reduces fuel consumption by approximately 22% at full load output and features a dual-fuel combustor capable of burning No. 2 fuel oil in addition to natural gas.

Figure 27: Mcintosh CAES facility



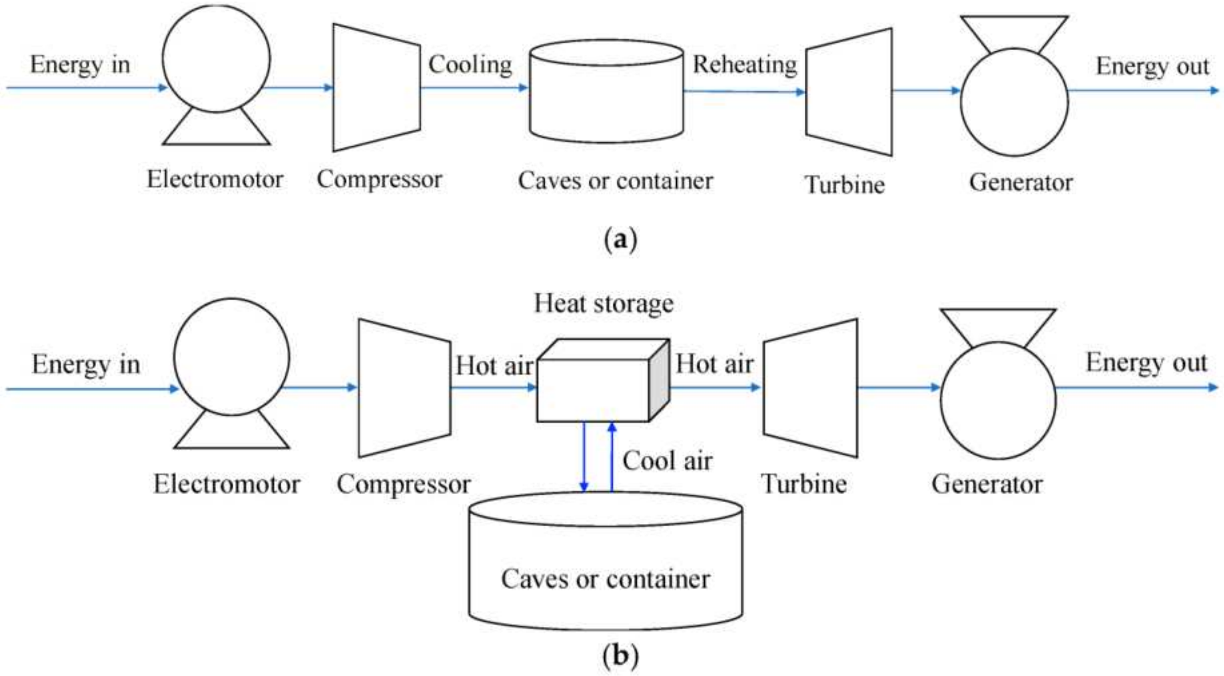
Source:https://acee.princeton.edu/wpcontent/uploads/2016/10/SuccarWilliams PEI CAES 2008April8.pdf

6.3. Working principle of technology

A compressed air energy storage (CAES) system lacking heat storage comprises three essential components: air compression, air storage, and power generation. The air compression unit includes an electromotor and a compressor responsible for raising the air pressure to a predetermined level. During the compressing process, the air temperature increases, which makes it difficult to compress the air further. Therefore, the air should be cooled during compression[102].

The power-generating unit is composed of multistage turbines and a generator, and extracts energy by expanding the compressed air. The compressed air flows through the turbines and changes into cold air with low pressure. To increase the efficiency of the system and prevent the temperature of the air from being too low, the compressed air should be heated by burning natural gas or electric heating[103].

Figure 28: Working Principle of CAES

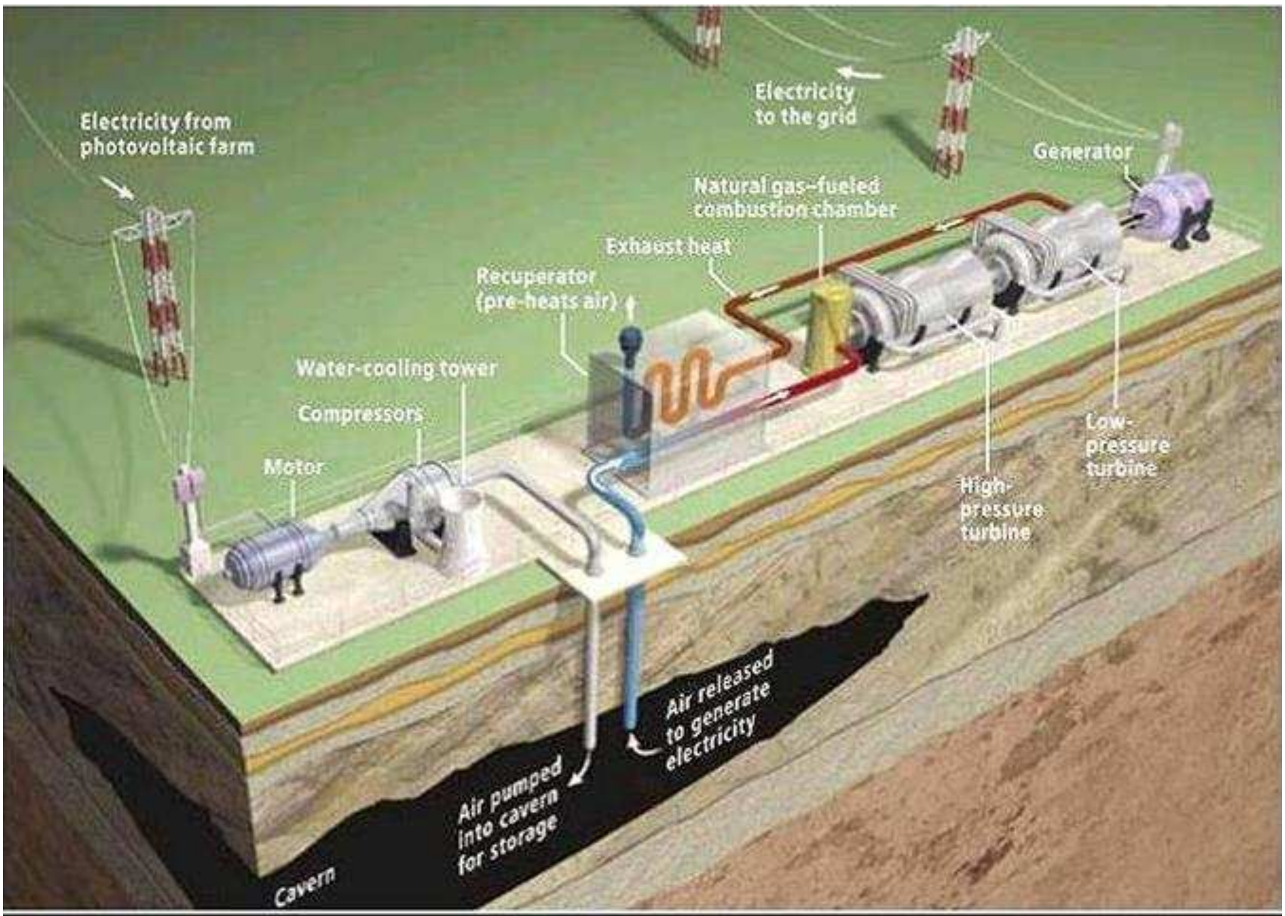


Source: https://www.mdpi.com/1996-1073/12/21/4188

One of the confusing aspects of the diabatic CAES is the requirement for additional fuel in the expansion process. The magnitude of expansion envisioned in the CAES expander systems is such that the outflow of the turbine without heat being added would be nearly cryogenic in nature, making the design of the turbines problematic[104]. In addition to diabatic CAES, adiabatic CAES (A-CAES) has been proposed in recent years to avoid using fossil fuels in the discharging of the energy storage process. Using thermal energy storage (TES), ACAES collects and stores heat from the air compression process during the charge period, and reuses that heat instead of fossil fuels to raise the air discharge temperature at the expansion stage. Besides independence of fossil fuels, A-CAES is expected to have higher cycle efficiency than the conventional CAES plants[105].

As the air should be cooled during compressing and heated before flowing into the turbines, a lot of energy is wasted, and the efficiency of the CAES system is low (approximately 42% for the plant in Germany). Thus, an advanced CAES system with heat storage is a better option in terms of efficiency. In the advanced system, the heat during compression is stored in a heat-exchanging unit, and the final compressed air is at approximately room temperature. When generating electricity, the compressed air first flows into the heat-exchanging unit and is heated to high temperature, then expands in the turbines. The advanced scheme has a much higher efficiency (over 60%)[106].

Figure 29: Graphical Representation of CAES



Source: https://www.ctc-n.org/technologies/compressed-air-energy-storage-caes

6.4. Conditions determining suitability of technology

Installation of CAES technology at a mine site requires considerable evaluation to ensure safety, efficiency and cost effectiveness. The compressed air storage site should be chosen considerably in order to avoid any hazard caused by inflammable gases present in underground coal mines. It is very important to note that the carbon seams, due to organic matter, have methane in their pores. Compressed air in contact with coal seams may cause spontaneous combustion of coal and as a result uncontrollable fire. To avoid risks, only drifts that do not have coal, should be used for compressed air storage.

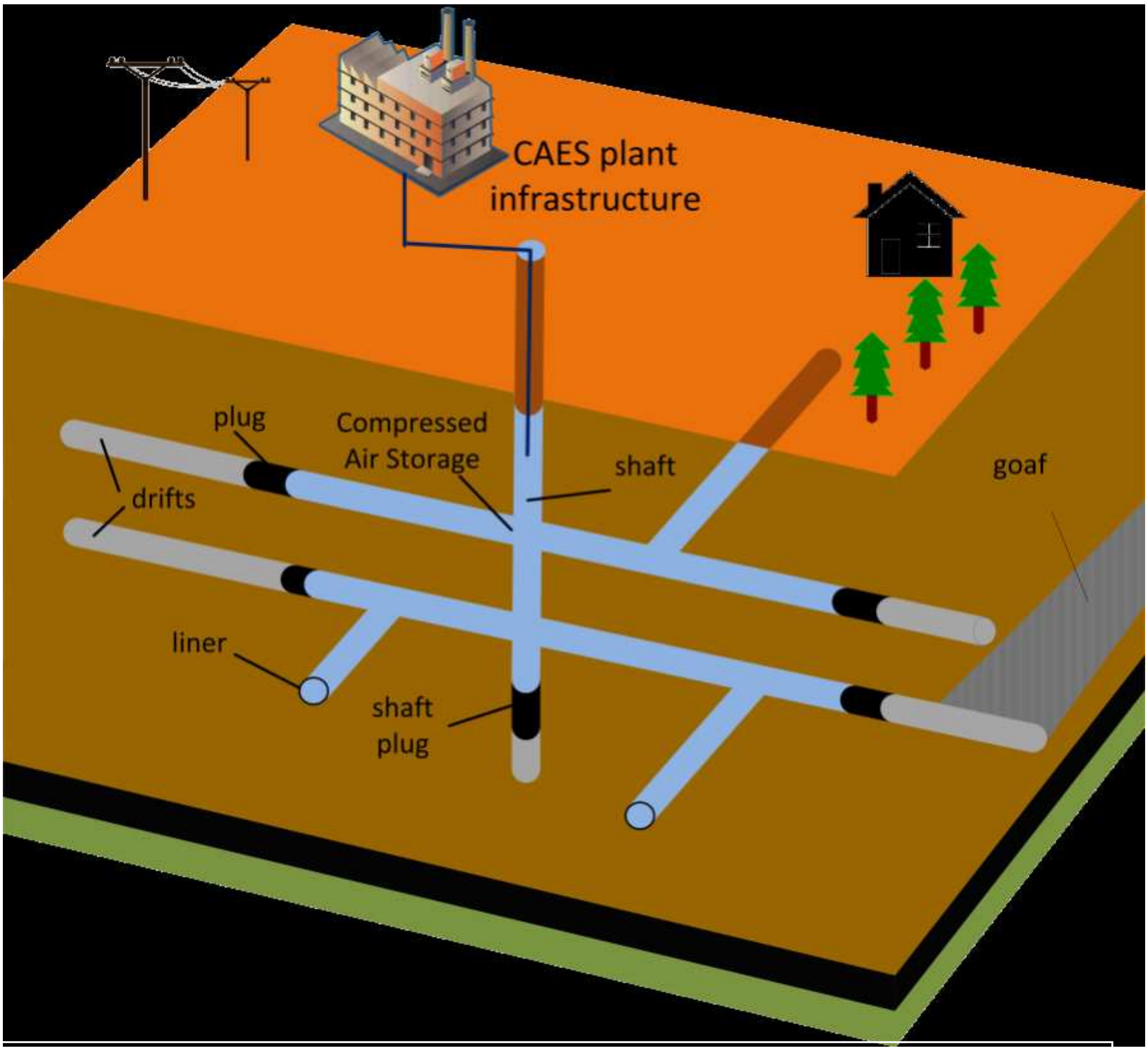
There is a possibility to store compressed air in abandoned coal mines if the drifts and shafts are properly sealed and separated from the remaining coal seams. The underground coal mines in India can be used to store compressed air by sealing of underground workings from the remaining coal seams and drifts which may be prone to collapse or deformation and applying liners on the surface of drifts and shaft in contact with air to prevent leakages[107].

Therefore, starting with any concept related to CAES in closed coal mines, the following conditions have to be considered:

- The current galleries should be sealed and reinforced with a layer of shotcrete.
- Inflow of water has to be either controlled or location should be in dry mines.

- Workings accessible for air should be isolated with liners, plugs or stoppings designed to withstand high pressures in storage facility[108].

Figure 30: Use of UG coal mines for storing compressed air



Source: https://iopscience.iop.org/article/10.1088/1757-899X/268/1/012006/pdf

Some more important factors to consider while determining suitability of the technology are as follows:

- **Energy source –** The energy source to power the air compressor should be present near the power generation facility.
- **Storage capacity –** The storage capacity should be able to provide buffer during peak demand.
- **Geotechnical parameters of storage site –** The storage site should have the strata to withstand high pressures of upto 8 – 10 mega pascals.
- **Safety –** The ingress and outgross to the storage site should be well maintained and monitored continuously for the strata integrity.

6.5. Potential for symbiosis with other repurposing options

Table 15: Potential symbiosis with compressed air storage

Repurposing options	Degree to which options can be combined
Floating solar	Excess energy generated by the floating solar plant can be used to compresses the air in the abandoned underground mines. When electricity demand increases, the compressed air is released to run the turbines, generating electricity to meet the demand. The combination of these two options is an eco-friendly solution to manage the energy demands.
PV on mine land	The storage technology used for both stand-alone and grid-connected PV systems is based on batteries, but others solutions such as compressed air energy storage can be considered. From the life cycle assessment used to compare Energy Storage System (ESS) of different nature, it emerged that the traditional CAES have the highest Energy Storage On Energy Invested (ESOI) index of 240. ESOI is the total amount of energy stored over the lifetime of a storage technology unit, divided by the amount of energy used in producing that unit, i.e. kWh/kWh. Among the batteries Li-ion has the highest ESOI, that is 10, evidently much lower than CAES[109].
Wind Power	The major challenge of wind energy while integrating into the electrical grid is that the resource is intermittent and unpredictable. With an energy storage system integrated with wind turbine, surplus energy can be stored and then regenerated when demand is higher. With CAES system energy is stored prior to electricity generation, eliminating the need and losses associated with generating electricity twice[110].
Thermal energy	The adiabetic CAES cycle stores energy in the cavern in form of pressure, while compression heat is stored in a thermal storage. For re-electrification both forms of energy are being utilized. No additional fuel is needed to heat up the released air[111].

Source: PwC Analysis

This type of storage has a vast potential of storing energy and it depends on the area available for air storage. This option can be coupled with thermal energy storage and other renewable energy options and with other storage options as well. The detailed analysis for this option has been done in section 26.

6.6. Potential environmental impact locally and GHG emission reduction potential

There are several environment impacts than can effect local population due to the use of CAES such as the noise levels may rise, depletion of water resource due to its use in cooling the hot compressed air. Any kind of contact between compressed air and coal seam due to leakage in the system may result in a mine fire which can have huge impact on the ambient air quality.

The potential for greenhouse gas (GHG) reduction in a compressed air storage system is influenced by several factors. These factors include the energy source employed for air compression, system efficiency, energy losses, air leakage, and other operational considerations. Remarkably, even when the process involves heating the air using fossil fuels, a compressed-air energy storage system typically emits fewer carbon emissions per kilowatt-hour (kWh) than operating a natural gas power plants conventional compressed-air energy storage releases approximately 228g of CO_2 per kWh, which is" less than the 388 grams of CO_2 per kWh reported for the combined cycle gas turbines used in gas power plants[112].

6.7. Employment effects

CAES requires technical expertise but also creates jobs in other aspects of the project as described below.

Table 16: Direct & indirect employment created by CAES facility

Direct Employment	Indirect Employment
Manufacturing of components	Workers in hotels and lodges
Transportation of equipment, material and workmen	Restaurant employees
Electrical and mechanical installation such as turbines, generators, compressors and control systems	General stores workmen
System operators	House help
Maintenance crew	People involved in Laundry & dry cleaning services
Safety and security crew	People working on tea stalls and other small vendors
Administrative people	Local transporters
Research & development specialist to continuously upgrade the system	Small maintenance and repair shops

Source: PwC Analysis

Direct employment refers to jobs that are directly created by a specific business or industry. These are the jobs within the core operations of the company and are directly related to its primary activities. Indirect employment, on the other hand, refers to jobs that are not directly within the core operations of a business but are created because of the economic activity generated by that business or industry.

6.8. Economic feasibility analysis

We have prepared an economic model based on the installation of compressed air energy storage plant on an abandoned underground mine for which assumptions taken are tabulated below.

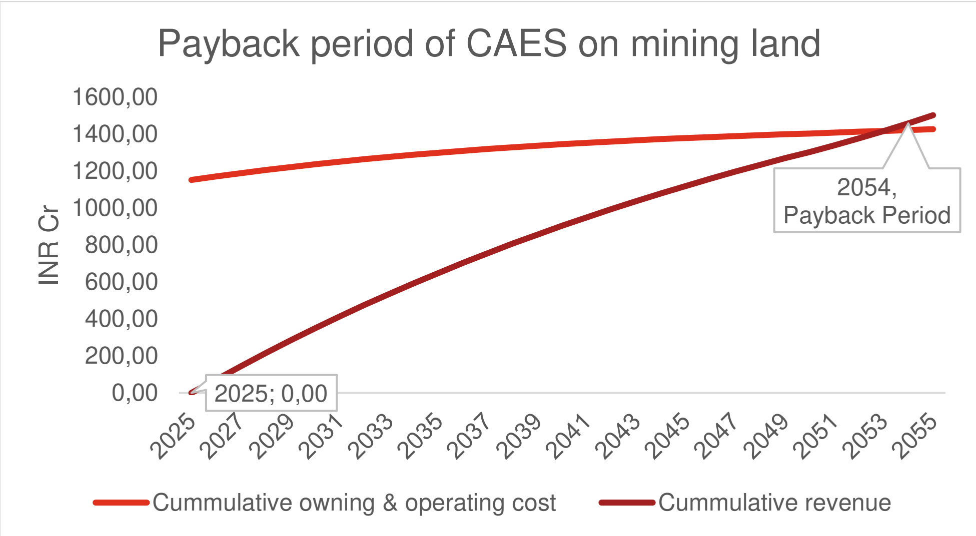
Table 17: Assumptions for economic model of CAES at mine site

S.No.	Parameters	Value	Remarks
1	Size of project	110 MW	
2	Life of project	30 Years	
3	Capital cost	1153 INR Cr	2020 Grid Energy Storage Technology Cost and Performance Assessment, Technical Report, Publication No. DOE/PA-0204
4	Opex	22 INR Cr	2020 Grid Energy Storage Technology Cost and Performance Assessment, Technical Report, Publication No. DOE/PA-0204

5	Escalation on Opex	2%	PwC Analysis
6	Electricity produced	145.2 million kwh	PV Magazine article, World's largest compressed air energy storage project goes online in China dated oct 6, 2022
7	Selling price of electricity	5.82 INR / kwh	PwC Analysis
8	Escalation on selling price	5%	PwC Analysis
9	Discount rate	8.5%	

Source: PwC Analysis

Chart 1: Payback period of CAES at mine site



Source: PwC Analysis

6.9. Pros and cons

Table 18: Pros and Cons of compressed air storage

Pros	Cons
High storage volume: Salt caverns and underground mines generally have high capacity for storing compressed air which subsequently enhancing the duration of power generation.	**Energy losses** – In the CAES system the electrical energy is converted to mechanical energy and vis versa which reduces the overall efficiency of the system.
Long project life: CAES tend to have a longer lifecycle compared to some other energy storage technologies like batteries, which may require replacement more frequently.	**High initial cost** – The initial capital investment for setting up a compressed air storage system is generally high.

Efficiency: The system has higher efficiency than most of the storage options in case of adiabatic CAES.	**spontaneous combustion of coal** – There are chances of mine fire due to spontaneous combustion of coal. It is necessary to build stopping in underground mines and cover the area to prevent expansion of fire.
Diverse deployment – This technology can be deployed above the ground in which storage tanks are used and below the ground in which salt caverns or underground mine drivage's are used.	**Drop in pressure** - Storage cavern pressure drops due to adsorption of air on coal surfaces which requires more energy during expansion stage and may reduce the efficiency of the system.
Safe – CAES is safer than other storage technologies as they do not involve toxic chemicals and flammable materials.	**Geological and location constraints** - Traditional underground CAES systems require suitable geological formations, which may not be readily available at all mine sites.
Low excavation cost - The excavations already exist and the geology of the site is relatively well recognized.	

Source: PwC Analysis

6.10. Suitability for India

Compressed air storage has not yet been developed in India, but since there are number of abandoned underground mines present in India, the potential to set up this energy storage option is high. With proper policies, incentives, technological development and infrastructure in place, CAES can be set up in the abandoned mines in India.

Considering the working principle of this technology and the conditions determining suitability of CAES, the suitability of CAES in abandoned coal mines have been analyzed in detail in Section 27.

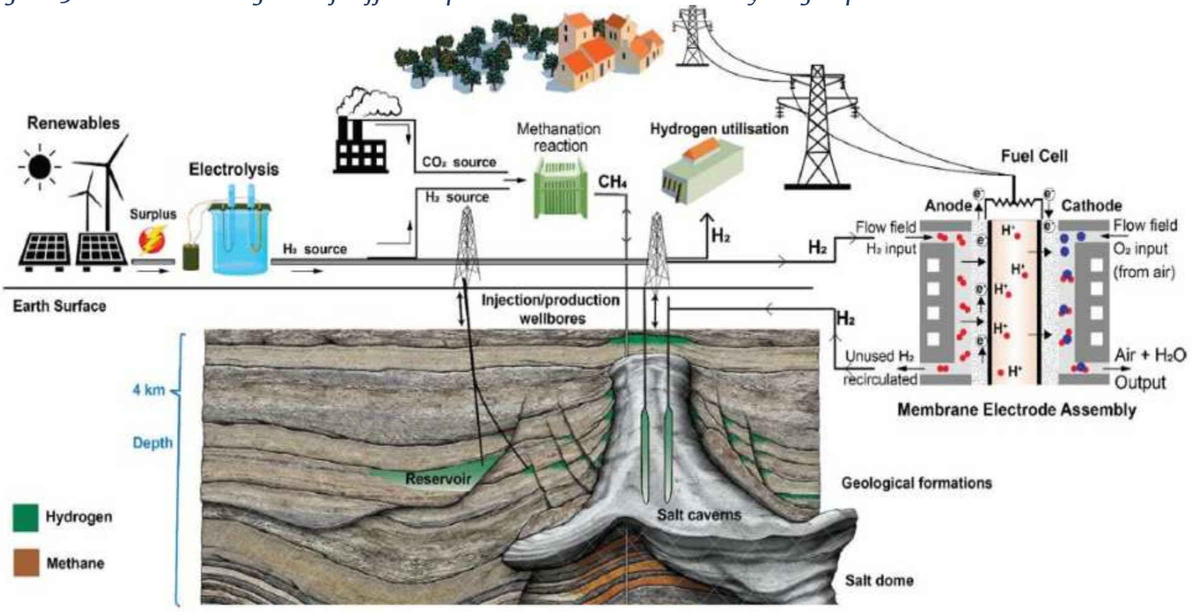
7. Hydrogen Storage - As Repurposing option

7.1. Introduction to repurposing option

Decarbonizing the global energy system has been a priority for governments and various organizations. Research and efforts are made in the direction of improving the energy efficiency, to add more renewable energy options, and to bring behavioral change among the people. Hydrogen is one such option which is being considered as an alternative to fossil fuels, due to its clean combustion properties and growing demand in the sectors like transport, heavy industry, etc. Hydrogen storage is one of the key technologies which will be responsible for making hydrogen fuel a success. Hydrogen has the highest energy per mass of any fuel, but it has low energy per unit volume due to its low density at ambient temperatures. Therefore, it is important to store the hydrogen properly to get the maximum energy out of it.

Research has been done to find the options for storing hydrogen, and it has been found that coal beds are one of the best options to store hydrogen. The abandoned coal mines can serve as the location to store the hydrogen gas and additionally they can provide land for integrating them with other renewable energy options thus making a hybrid system which will be more effective and beneficial. It has been found that the coal has lot of pores that can hold the gas until it is pumped out when needed. Hydrogen sticks to coal walls due to absorption and thus can be stored in the abandoned mines. Also, because of low energy per unit volume, it is essential to store hydrogen in large volumes, which is challenging if stored on ground, and therefore abandoned mines get advantage due to the large voids underground which will help to store large volume of hydrogen. The following figure shows a schematic diagram of different processes which are associated with hydrogen production using electrolysis, seasonal storage in geological formations and/or salt caverns, utilization for ammonia production and re-electrification of hydrogen using fuel cells.

Figure 31: Schematic diagram of different processes associated with hydrogen production



Source : https://link.springer.com/article/10.1007/s10311-021-01322-8

Hydrogen storage is a developing technology and is still in the phase of research and development. There have been 5 underground hydrogen storages in the world, which are situated in Teeside, UK; Clemens, USA; Moss Bluff, USA; Spindletop, USA; and Kiel, Germany that store hydrogen gas in the salt caverns. Research is being done to make underground hydrogen storage more feasible by mixing it with other gases. Some developments like the Sun Storage, SAG Austria and Hychico are working on underground methanation using combined hydrogen and carbon dioxide injection.

7.2. Global best practices with examples

Hydrogen storage has been in development on a global scale and is mostly stored in the salt caverns. As of now there are 5 underground hydrogen storages that have been built in the world[113].

7.2.1. Clemens, USA

The Clemens salt dome was a former sulphur production plant but now stores around 580,000 m^3 of hydrogen at a pressure of 150 bar. It has the 95% hydrogen which generates electricity upto 892 GWh. This underground hydrogen facility has been operational since 1986 and the depth of the cavern is 850 m[114].

7.2.2. Teeside, UK

This salt cavern has been operational for past 35-36 years and has a capacity of total 210,000 cubic meter of hydrogen. It has three unit of 70,000 cubic meter each and has 95% hydrogen stored at a pressure of 45 bar. This stored hydrogen is utilized to generate electricity up to 30 GWh. The storing units are at a depth of 370 m[115].

7.2.3. Moss Bluff, USA

This underground hydrogen storage has a total capacity of 566,000 cubic meter and the gas is stored at a pressure varying from 70-135 bar. This underground storage facility has been operational since 2007 and can produce electricity up to 80 GWh. The depth at which the hydrogen is stored varies from 850 m to 1400 m[116].

7.2.4. Spindletop, USA

Spindletop underground hydrogen storage has a capacity of 600,000 cubic meter. It stores 95% hydrogen at a pressure of about 150 bar. This salt cavern is at a depth varying from 850 m to 1400 m[117].

7.2.5. Kiel, Germany

The salt cavern in Kiel was operational from 1971 but it is closed now. It stored 62% hydrogen at pressure varying from 20 to 100 bar. This salt cavern was at a depth of 1335 m[118].

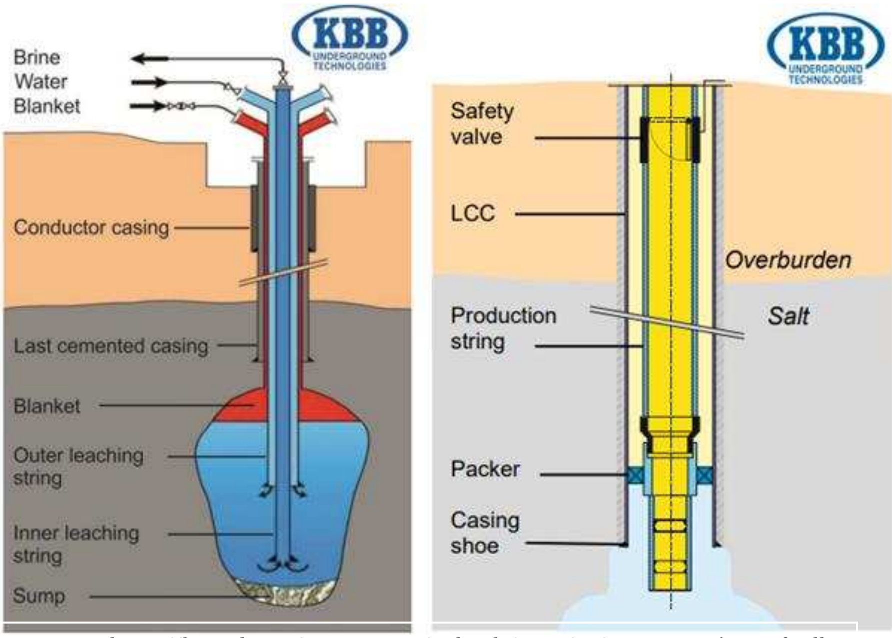
7.3. Working principle of technology

Storing Hydrogen at surface level is very risky and challenging because of its low density and therefore it must be stored at high pressures and so the best option to do so is underground storage. Currently the best proven subsurface for hydrogen storage is salt caverns. Because salt is made of rock, salt caverns are gas tight. Thick layers of sealing salt are combined with this gas tightness by the salt pillars with significant widths and thicknesses beneath, above, and below the cavern, respectively, which are necessary for the rock mechanical stability of the host rock. The cavern depth, operational plan, and other factors determine the applicable storage pressures. fall about 80% and 30% of the lithostatic rock pressure. At a typical 1,000 m cavern top depth, which translates to a maximum pressure of about 180 bar and roughly 65 bar at minimum pressure[119].

Generally, the gas caverns are operated on sliding pressure mechanism which involves compression and decompression between a minimum and maximum pressure. The gas stored in the salt cavern is of two types:

- Working gas - which is the main gas and can be withdrawn from the cavern during normal operations.
- Cushion gas - which must remain in the cavern to ensure the stability of the structure. Certain strings are installed in the salt caverns to make it compatible to use for gas operations which can be seen in figure below.

Figure 32: Preparedness of salt caverns for hydrogen storage



Source : https://hyunder.eu/wp-content/uploads/2016/01/D3.1_Overview-of-all-known-underground-storage-technologies.pdf

The pressure for injection and withdrawal of the gas varies between the maximum and minimum pressure. Apart from this, the salt cavern operations are mainly restricted by the maximum pressure change rate per unit time to ensure stability and by maximum flow velocities inside the wall. Sometimes the gas operation is done at the constant temperatures too[120].

7.4. Conditions determining suitability of technology

Since hydrogen has low energy per unit volume, it requires large volumes to store it and make it feasible. Also, hydrogen has low viscosity and high diffusivity due to which it is important to understand the conditions of the storing unit before using it, the conditions are[121]:

- **Available gas storage space**: It is one of the most important factors to make hydrogen storage economically feasible. The volume available to store the gas should be more so that the benefits of storing the gas underground can be maximized.
- **Airtightness treatment**: Airtightness treatment for the volume should be sufficient to stop the leakage of the hydrogen from the storing unit. Hydrogen being a flammable and explosive gas it is very important to keep the airtightness treatment proper.
- **Rock mass stability**: Due to the injection of the gas on a periodic basis, there is a change in the stress rate and the stability of the rock mass. So, in order to keep the hydrogen storage safe and keep the reconstruction cost at minimal it is important to ensure that the land has required rock mass stability.
- **Fault Fissure development degree**: Development of faults in the rock can affect the storage directly and can lead to possible leakage of the hydrogen gas.

There are several other factors which can be considered like the distance from nearest locality, possibility to integrate other renewable options.

7.5. Potential for symbiosis with other repurposing options

There is a possibility to integrate this storage option with other renewable options The detailed analysis for symbiosis of hydrogen storage with other option has been done in section 26.

7.6. Potential environmental impact locally and GHG emission reduction potential

Hydrogen has a great potential to be included as an energy fuel, 1 kg of hydrogen gas can generate 25.6 kWh of power considering the fuel cell efficiency at 65% leading to overall reduction of the carbon footprint of the energy sector. Till now hydrogen has been stored mainly in the salt caverns and the aquifers that has been utilized as an alternative fuel for the power. However, hydrogen storage is itself a big task and needs to be done carefully as it is highly flammable and explosive in nature and so the storage tasks need to be done with proper planning and technology to prevent any leakage[122].

7.7. Employment effects

Underground hydrogen storage can offer several jobs in various fields like:

- Research work of the underground cavity
- Construction of the storage cavity
- Construction of power plant or heater
- Manufacturing of the machines and parts
- Operating and maintaining the hydrogen storage

Underground hydrogen storage has scope to provide jobs directly and indirectly to research scholars, engineers local people etc.

7.8. Economic feasibility analysis

Underground Hydrogen storage (UHS) is in the developing stage, and research are going on to make hydrogen storage more feasible and economical. The research done show that underground hydrogen storage broadly has two major components:

1. Electrolysis Mechanism
2. Underground Storage

Hydrogen can be stored in three forms i.e., Liquid storage, Compressed gas storage and Cryogenic-compressed storage. But Liquid storage and Cryogenic-compressed storage require very low temperature and thus are not feasible and therefore hydrogen is stored in compressed gaseous form. Majorly underground hydrogen storage has been seen in Salt caverns, Depleted Gas Reservoirs or Aquifers. The cost of using salt caverns as a storage option for UHS is higher as compared to other options because the construction of Salt caverns for UHS is expensive.

Table 19 LCOS and CAPEX Costs for Hydrogen Storage

Type of Storage	LCOS (USUSD /kgH2)	LOCS (USUSD /kWh)	CAPEX (USUSD /kgH2)	CAPEX (USUSD /kWh)	Working Volume(tH2)
Salt Caverns	0.28	0.01	27.2	0.82	500
	1.4	0.04	51.5	1.55	1912
Depleted Gas Reservoirs	0.88	0.03	18.4	0.55	1912
Aquifer	0.89	0.03	19.3	0.58	1912

Source:https://www.gaffneycline.com/sites/g/files/cozyhq681/files/202207/gaffneycline_underground_hydrogen_storage_article.pdf

Some articles also mentioned that the hydrogen generation from low-cost renewables costs around USD 1.7/kg and underground hydrogen storage costs around USD 0.3/kg. If this hydrogen is used to generate power the resulting cost is USD 100 to USD 200/MWh depending upon the utilization of the plant[123].

7.9. Pros and cons

Table 20: Pros and Cons of hydrogen storage

Pros	Cons
Hydrogen Storage holds 150 times more energy than compressed air, it has higher energy per unit mass.	Underground hydrogen storage requires lot of research works to be done on the underground cavity to be utilized and thus has high upfront cost.
Hydrogen as a fuel can help in adding into the renewable energy portfolio of the country which is cleaner than other fossil fuels.	Hydrogen being lighter and highly flammable needs proper safety and care to prevent any kind of leakage
Building hydrogen storage in the abandoned mines will help in changing the negative reputation of the mining land and will bring back the reputation of the area and community	It is important to have a transmission access or a locality nearby to make this technology more feasible.
Communities can fulfill their energy demands with boom to local economy and employment by promoting the manufacturing the machines and materials required for the plant.	Cracks in the underground storage volume need to be checked regularly as hydrogen gas may leak into them and being flammable gas might cause threat to the structure
A state's and municipality's tax revenue may increase as of variety of stakeholders are involved	Getting a suitable location with difficulty is another disadvantage of this technology
Hydrogen is very versatile fuel and thus has multiple applications like electricity generation, heating buildings, power vehicles and produce industrial chemicals	

Source: PwC Analysis

7.10. Suitability for India

According to the Ministry of Coal, there will soon be availability of vast amounts of land as coal is phasing out gradually. Even 10% of the land will be able to produce 1mn MT of hydrogen annually. India consumes 7.5 MT of hydrogen annually. Thus, reclaiming and repurposing these coal mines for hydrogen production is very cost efficient as requirements like land and fresh water are fulfilled and existing infrastructure and resource will be utilized for hydrogen generation. It will also provide employment generation for people for whom these coal mines ae the sole source of income[124].

Considering the working principle of this technology and the conditions determining suitability of hydrogen storage, the suitability in abandoned coal mines have been analyzed in detail in Section 27.

8. Thermal Energy Storage - As Repurposing option

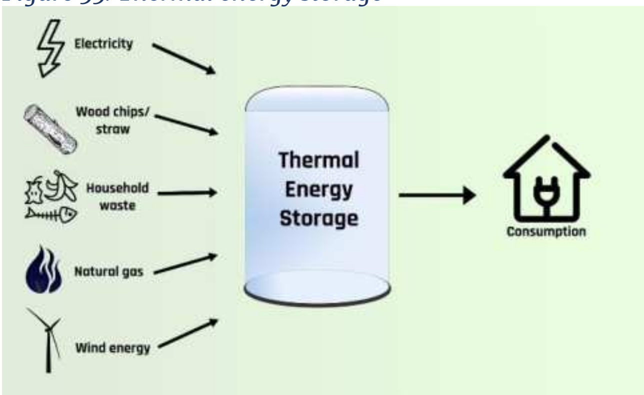
8.1. Introduction to repurposing option

Thermal energy storage refers to heating or cooling a storage medium, which then can be used to generated energy whenever it is required. Storing thermal energy helps to save and store the excess energy, that can be used later at any point, when there is demand of energy supply from other means.

There are three different types of thermal energy storage that exist:

Sensible heat storage: In this rock or water is used to store and release energy. It is considered the most viable option to reduce CO_2 emission and to reduce energy consumption as well. This storage option is viable to serve household communities.

Figure 33: Thermal energy storage



Source: https://www.senmatic.com/sensors/knowledge/thermal-energy-storage

Latent heat storage: In this the energy storage in not based on the change in temperature of the medium but is based on the change is state of the medium. This system uses "phase change material" that stores the heat as latent heat in its mass. There are generally used in solar application and are used in building materials, so that these can absorb the excess heat and store it.

Thermochemical heat storage: This system is not mature enough. It uses reversible chemical reactions to store the thermal energy[125].

8.2. Global best practices with examples

8.2.1. Thermosolar with thermal energy storage in Anantapur, India

The plant is located in Anantapur, a district of Andhra Pradesh. The district has an arid weather condition and receives daily solar radiation of 5.2 kW/m². And due to its natural condition Megha Engineering & Infrastructures Limited (MEIL) has established a 50 MW solar thermal plant. The plant is based on Concentrated Solar Power (CSP) and uses parabolic

Figure 34: Solar thermal plant at Annatapur, India

Source: https://www.newindianexpress.com/states/telangana/2014/nov/14/Anantapur-Gets-Solar-Power-Plant-682217.html

trough technology. The plant is spread across 600 acres of land and is built at a cost of INR 848 Crores[126].

8.2.2. Noor Solar Power Plant

Noor solar plant is a flagship project of the Moroccan Kingdom that is using the concentrated solar power (CSP) to generate energy. Located in Ghessate, Southern province of Ouarzazate, the first phase of the project Noor-I began in 2013 and was completed in 2016. In 2016, King Mohammed VI launched the constructions of two more phases Noor II and Noor III. Noor I and Noor II used 12 m tall parabolic mirrors to generate electricity, but Noor III will be using solar tower another variation of CSP. Another phase, fourth phase, is planned that would be using photovoltaic technology. The power capacity is of 580 MW with storage capacity of 7-8 hours, providing round the clock power generation for 1 million homes[127].

Figure 35: Noor power plant setup

Source: https://www.heidelbergmaterials.com/en/noor

8.2.3. India One Solar Power Plant

India One is a 1MW solar thermal power plant, that provides 16 hours of thermal energy storage enabling round the clock generation. The technology uses 60 m^2 parabolic reflectors with spaceframe structure that provides static focus at high temperature. The design of these parabolic dishes is such that the static focus helps to store the thermal energy at the focus point, eliminating the need of heat transfer fluids, reducing low pumping loads and is low maintenance. In this unique design, the static cast iron cavity receiver that is placed directly at the focus point, provides 24 hours of heat storage[128].

Figure 36: One India Solar Plant

Source: https://india-one.net/technology/

Other case study that can be referred to [Proposed installation of thermal energy storage site in an abandoned mine[129].]

8.3. Working principle of technology

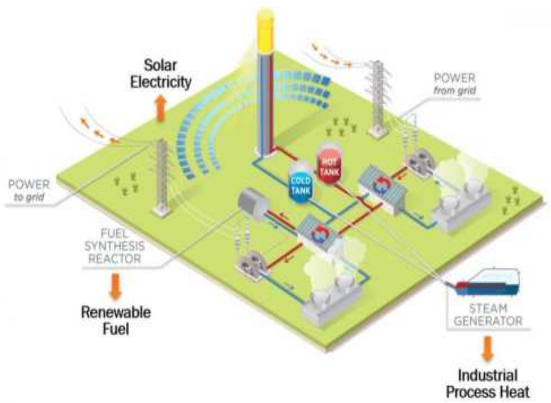
The working condition of the different types of thermal energy storage options have been detailed out below.

8.3.1. Concentrated Solar Power (CSP)

CSP use mirror reflectors to reflect and concentrate the sunlight on a receiver. A high temperature fluid is present in the receiver and gets heated up once the energy of the concentrated sunlight reaches it. The heat generated is used to spin the turbine or power the engine to generate power.

Working of CSP[130]

Figure 37: Concentrated Solar Power



Source: https://www.solarpaces.org/how-csp-

There are different types of CSP. The basic principle behind all the types remains the same, the difference lies in their designs. The four types of CSPs are as follows:

- **Solar Parabolic Dishes:** In this a parabolic reflector focuses the sunlight to a receiver that is mounted at the focal point, that absorbs the solar energy and produces heat. The dish moves according to sun's movement and to achieve this the structure has dual axis tracking and the movement is monitored a computer[131].

Working of parabolic dish[132]

- **Linear Fresnel Reflectors:** This uses flat mirrors to focus the sunlight on a fixed metal collector pipe that runs over the array of reflectors and is located at common point of focus of the reflectors[133].

  Working of linear reflectors[134]

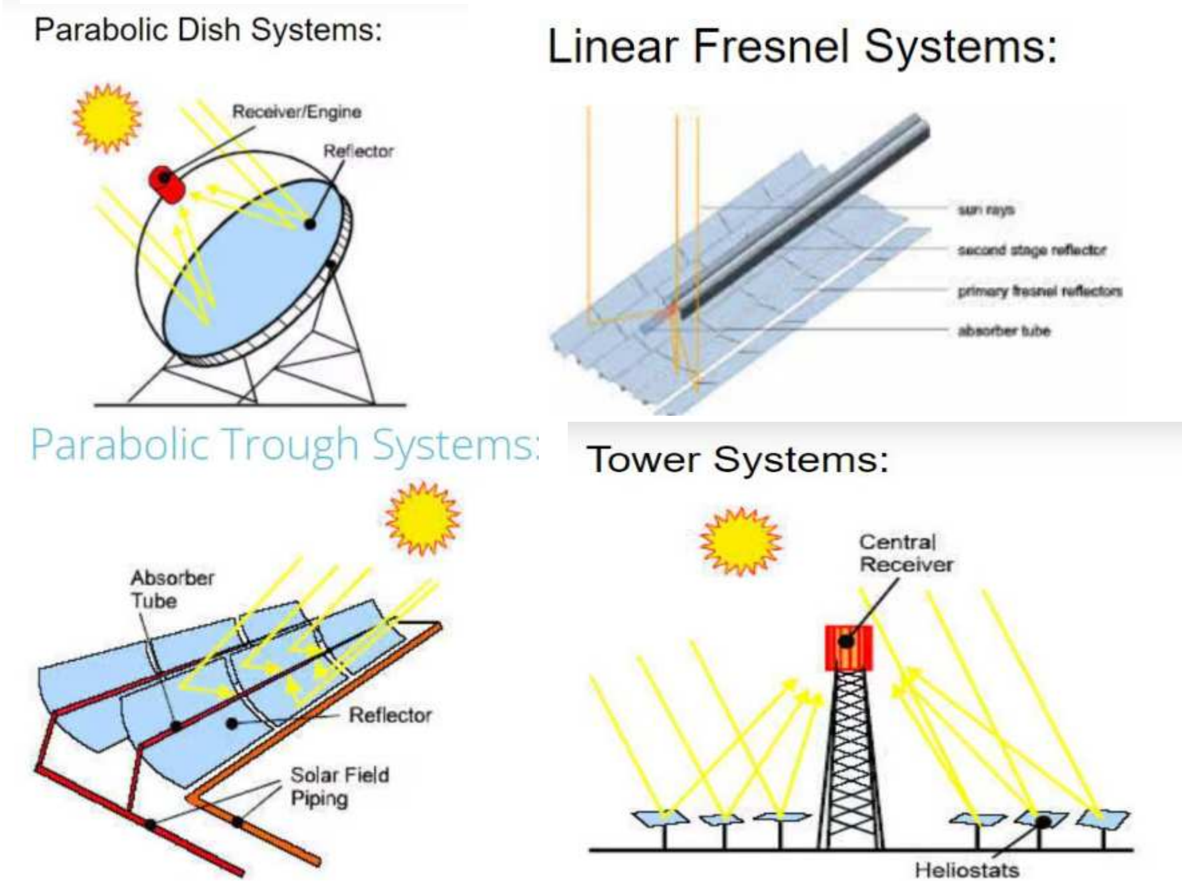
- **Parabolic Trough:** In these, reflectors or highly polished materials are used that are shaped in a parabolic shape. It moves according to the movement of the sun through the day. And the design is such at whichever part of the trough the sunlight falls, it gets reflected at the focal point. Parabolic trough has a large surface area, the energy from the sun gets reflected to the heat absorber tube, and the liquid within the pipe heats up which is used for power generation.

  Working of parabolic trough[135]

- **Power Tower:** It has a central receiver system, that uses heliostats, sun tracking mirrors, that focus the sunlight on the receiver situated at top of the tower. The heat transfer fluid in the receiver heats up to 600°C, releasing steam that is used to spin the turbine to generate electricity[136].

  Working of power tower[137]

Figure 38: Types of CSPs

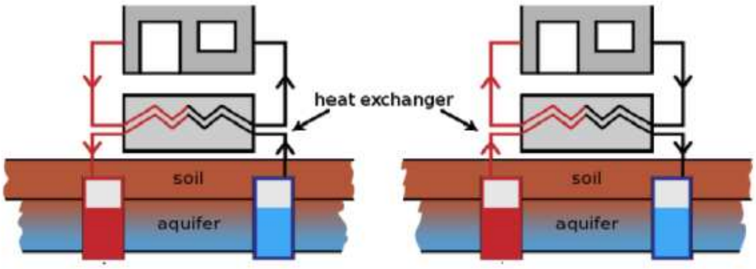


Source: https://www.solarpaces.org/how-csp-works/

8.3.2. Aquifer Thermal Energy Storage (ATES)

In this the thermal energy is stored in the ground water. The water is extracted from a well then is heated or cooled down before it is re-injected back into the ground. There are separate wells for warm water and cold water, so they don't mix. These are large systems

Figure 39: ATES for summer and winter



Left/ Summer - the ATES is used for cooling. Right/ Winter - the ATES is used for heating.

Source: https://www.diva-portal.org/smash/get/diva2:1003891/FULLTEXT01.pdf

that are mainly used as seasonal thermal storage for both heating and cooling purpose[138]. Working of ATES[139]

8.3.3. Cavern Thermal Energy Storage (CTES)

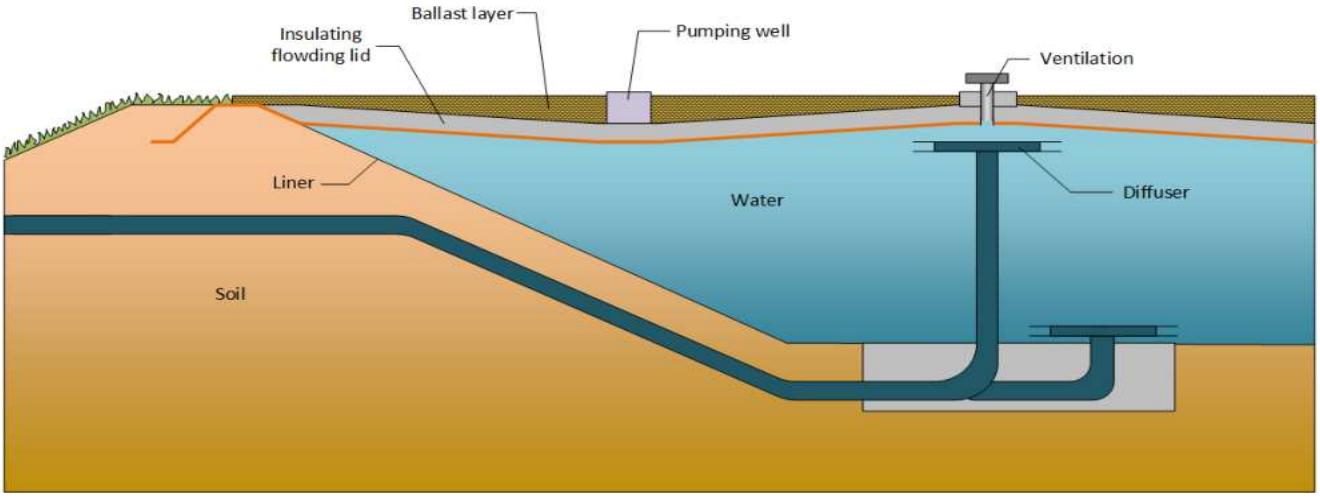
In this energy is stored in an underground cavern as hot water. This requires a large volume of water to maintain stratified temperature of the cavern. In this hot water is injected on the top at the time of injection and from the bottom, cold water is extracted[140].

8.3.4. Pit Thermal Energy Storage (PTES)

It is a large water reservoir that stores thermal energy. Excess heat from biomass plants, solar heating plants, industrial processes, wind turbines photovoltaic panels are used to heat up the water. When there is an increase in heat demand, the heated water is sent out to the customer, and the cooler water from the district heating plant is filled in the bottom of the plant. Thus, when there is high demand heat is realized, otherwise it is stored in the water.

For this the reservoir is lined with waterproof plastic lining to trap the heat and to prevents the heat being absorbed in the surrounding soil, and the top is covered with a floating insulated cover that retains the heat and prevent rainwater to enter the reservoir[141].

Figure 40: Pit Thermal Energy Storage



Source: https://www.aalborgcsp.com/business-areas/thermal-energy-storage-tes/pit-thermal-energy-storage-ptes

8.4. Conditions determining suitability of technology

The conditions required to set up the different thermal energy storage options need to be assessed to understand which option will be best suited for a particular abandoned mine.

8.4.1. Concentrated Solar Power (CSP)

- **Area with high solar radiation:** The major component for CSP is the sunlight, and the heat and radiation of it. It is measured by direct normal intensity (DNI) that is amount of solar radiation that is received by a surface of per unit area. So CSP should be installed at a place that has ample amount of sunlight throughout the day. As if the sunlight is diffused then CSP will not operate efficiently.
- **Area of land:** Around 5-10 acres of land is required per MW of generation capacity. A CSP plant runs efficiently and is cost-effective when it is built with a capacity of 100 MW or higher.
- **Water resource:** CSP systems require water to cool down the systems, clean the mirror surfaces, etc. The plants that use dry, wet and hybrid cooling techniques can maximize electricity generation efficiently, and also ensure water conservation.
- **Access to transmission facility in proximity:** CSP plants must be set up on a site that is suitable for power generation and has access to high voltage transmission lines, to develop utility scale power plants. This makes transmitting electricity from power plant to end user very convenient[142].

8.4.2. Aquifer Thermal Energy Storage (ATES)

The depth of the wells for aquifer systems varies between 20-200 meters. The temperature of the cold storage ranges between 10-20° C and the heat storage is generally at 80°C.

It also requires that suitable aquifers are present. Like, a solid rock limits access, but a sandy aquifer is suitable. Hydraulic conductivity is required but it should be ensured that that the groundwater flow is not excessive as that may transport the stored energy out of the well[143].

8.4.3. Cavern Thermal Energy Storage (CTES)

A future CTES is being designed for small units like a 3-floor building with a 1,000 square meter of footprint. It is estimated that the building would require 77 MWh of energy, for winter, and around 66MWh of energy needs to be stored. So for this a water body of 1,600-7,600m^2 is required[144].

8.4.4. Pit Thermal Energy Storage (PTES)

Since there is no major construction cost involved, storage geometries like pyramid stumps with rectangular cross-sections and truncated cones with circular cross-sections designs with slopes can be developed[145].

Insulation and liner material are of utmost importance, as this helps in retaining the thermal energy within the storage. The top layer prevents energy loss from the top and the liner prevent in to get penetrated in the soil. These layers also prevent from seepage of the water and rainwater from entering the storage.

8.5. Potential for symbiosis with other repurposing options

Table 21: Potential symbiosis with thermal energy storage

Repurposing options	Degree to which options can be combined
Wind Energy on Mining Land	A thermal energy storage system mainly consists of three parts, the storage medium, heat transfer mechanism and containment system. The thermal energy storage system modeled, uses two-tank-direct configuration where the heat transfer fluid (HTF) also acts as the energy storage medium. It requires two separate tanks, eliminating the need of a heat exchanger to transfer heat from the collected HTF to the storage medium. The fluid gets stored at its lower temperature in a cold tank, and is heated by mechanical work from wind turbine, and then gets stored in the hot tank at an elevated temperature. The energy stored in the hot tank is delivered to the load by pumping the HTF through the boiler. It is assumed that saturated liquid water is fed to the boiler and it exits as saturated steam. Here, the HTF cools down in the exchanger and is pumped back to the cold tank. The output power is represented by the flow rate of the saturated steam generated in the boiler[146].
PV on Mining Land	Solar thermal power plant, a combination of solar energy and thermal energy, where the sun's radiations is used to fuel the power plant. Solar energy is converted into thermal or heat energy which is then converted into mechanical energy through turbine and energy is generated using generators[147].
Recreational Parks	Thermal can be used to for various purposes in a recreational park, like providing lighting, signposts, information kiosks, pergolas, Electrical vehicle charging stations, Solar-powered Trash Compacting Facilities, Energy for furniture and buildings on the area, etc.[148]

Repurposing options	Degree to which options can be combined
Ecotourism	Thermal can be used to for various purposes in a ecotourism, like providing lighting, signposts, information kiosks, pergolas, Solar-powered Trash Compacting Facilities, etc.
Horticulture	Land required for horticulture is subjective to availability, so can be set up with ease. And thermal energy is quiet beneficial for horticulture as mentioned below: • Generated heat is available round the clock • Makes systems run more efficiently • Makes heat generators smaller • Allows multiple heat generators to coordinate effectively • Provide heating backup
Pumped Storage Hydropower	Combining thermal energy storage with PSH ca increase the efficiency and flexibility of the system. Heat can be stored during low energy requirement, and during high electricity demand, the stored heat can be used to increase the efficiency of PSH by preheating the water before it enters the turbines. The integration allow better manage the fluctuating energy requirements.
Compressed Air Energy Storage	The adiabetic CAES cycle stores energy in the cavern in form of pressure, while compression heat is stored in a thermal storage. For re-electrification both forms of energy are being utilized. No additional fuel is needed to heat up the released air[149].

Source: PwC Analysis

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure needs and requirement of the options are quite different, but certain parameters like environmental benefit by the options, stays quiet similar.

8.6. Potential environmental impact locally and GHG emission reduction potential

- **Reduced dependence on nonrenewable energy:** Since thermal energy is being stored, and with technological developments, thermal energy is able to provide round the clock power supply, hence reducing the use of fossil fuels and other carbon emitting sources hence reducing the greenhouse gas emission.
- **Utilization of renewable energy:** Excess energy generated by renewable sources like wind, solar, etc. is stored, and can be distributed, when there is shortage or excess need.
- **Energy efficiency:** The energy generated during low-demand, or off-peak hours is stored, that reduces energy loss, ensuring efficiency in energy utilization.
- **Grid stability:** Since the energy is stored during low demand, there is a buffer which can be provided during peak hours or when supply is short from other sources. This ensures that there are no blackouts, and the grid remains stable as a result.
- **Smart management:** TES ensures smart energy management, by charging and storing the energy, thus when there is high demand, energy can be supplied, reducing dependency on coal and fossil fuels to generate energy, ensure a green and better future[150].

8.7. Employment effects

Thermal energy storage projects can generate employment opportunities at various stages as explained in the table below.

Table 22: Components of employment

Direct Employment	Indirect Employment
Site Preparation for installation	Hotels and lodges
Geotechnical evaluation of the site	Restaurant
Electrical and mechanical installation	General stores
Transportation of equipment, material and workmen	House help
System operators	Laundry & dry cleaning
Maintenance crew	Tea stalls and other small vendors
Safety and security crew	Local transporters
Administrative people	
Research & development specialist to continuously upgrade the system	

Source: PwC Analysis

Direct employment refers to jobs that are directly created by a specific business or industry. These are the jobs within the core operations of the company and are directly related to its primary activities. Indirect employment, on the other hand, refers to jobs that are not directly within the core operations of a business but are created as a result of the economic activity generated by that business or industry.

8.8. Economic feasibility analysis

We have prepared an economic model based on the installation of solar thermal plants on abandoned mines for which assumptions taken are tabulated below.

Table 23: Assumptions for economic model of Thermal energy storage

S.No.	Parameters	Value (Parabolic Trough)	Value (Power Tower)	Remarks
1	Size of project	50 MW	50 MW	
2	Life of project	25 Years	25 Years	
4	Capital cost	9980 INR Cr	8816 INR Cr	https://www.mdpi.com/2673-9941/3/1/10
5	Opex	81.90 INR Cr	73.19 INR Cr	https://www.mdpi.com/2673-9941/3/1/10
6	Escalation on Opex	2%	2%	PwC Analysis
7	Electricity produced	219,000 MWh	219,000 MWh	PwC Analysis

S.No.	Parameters	Value (Parabolic Trough)	Value (Power Tower)	Remarks
8	Selling price of electricity	INR 5.95/kWh	INR 5.95/kWh	PwC Analysis
9	Escalation on selling price	5%	5%	PwC Analysis
10	Discount rate	8.5%	8.5%	

Source: https://www.mdpi.com/2673-9941/3/1/10

The capex cost seems to be at a higher end for thermal energy storage plant due to which the economics of the project is a cause of concern for setting up thermal energy storage at a mine site.

8.9. Pros and cons.

There are various advantages and disadvantages of thermal energy storage. Some of them are as follows:

Table 24: Pros and Cons of thermal energy storage

Pros	Cons
Since renewable sources are used to generate the electricity, the energy source is easily available and free to use.	Setting up renewable plants is expensive, and setting up on a large scale multiplies the cost.
Doesn't harm the environment, as renewables sources neither generates greenhouse gases nor emits carbon.	There are certain options that has low energy density and leads to heat discharge, leading to energy loss for a long run.
During off-peak hours, energy is stored which is realized when demand is high or there is shortage of supply ensure stability of the grid.	If the storage medium degrades, it leads to decrease in the thermal storage capacity of the medium.
Energy is utilized in the most efficient manner, as it gets stored when in excess and is utilized when there is a shortage.	
Employment and revenue generation	

Source: PwC Analysis

8.10. Suitability for India

Thermal storage has not yet been set up on any abandoned coal mine, but the potential to set one up is quite favorable. The area of mines is huge, and both open cast and underground mines are present across the states, enabling to set up the most suitable thermal storage according to the geographical and topological factors. Additionally, incentives, policies and favorable technological advance will help in working of the technologies more efficiently.

Loan Scheme to promote the Concentrating Solar Thermal (CST) Projects in India for Industrial Process Heat Applications

Ministry of New & Renewable Energy (MNRE) in partnership with United Nation Industrial Development Organization (UNIDO) and IREDA under the GEF-UNIDO-MNRE project launched an innovative financing scheme to promote adoption of Concentrated Solar Thermal (CST) Technologies for thermal applications in the specified industrial sectors.

The Loan Scheme

The scheme aims to provide financial assistance to beneficiaries to overcome the financial constraints faced during adoption and penetration of CST technologies. Under this scheme, financial assistance is available for up to 75 % of the CST project costs[151].

Scheme Highlights

PART A: Soft loan from IREDA

- Rate of Interest is 7%, after considering UNIDO interest subvention.
- Repayment Period is 7 years, 1 year moratorium + 6 years repayment.

PART B: Bridge loan against MNRE subsidy

Rate of Interest is 12%. The rate is applicable till the project is commissioned. On commissioning, the MNRE subsidy will be passed to the project and the bridge loan will be closed.

Indicative Project Cost Structure:

Minimum promoter's contribution - 25%

Soft Loan - 45%

MNRE Subsidy - 30%

Total - 100%

Note: Quantum of Soft Loan will depend on the MNRE subsidy and approval by UNIDO-PMU.

Projects Eligible for Assistance

Any entity as per IREDA guidelines setting up a solar thermal heating/ cooling/ trigeneration project.

General Applicant Eligibility Norms as per prevailing IREDA financing Norms

Minimum Loan Amount - The minimum loan eligibility from IREDA will be INR 30 lakhs.

Disbursement Schedule - The disbursement schedule is applicable for both Soft Loan and Bridge Loan.

Table 25: Disbursement Schedule

Installment	Percentage	Terms
1st instalment	30 % of loan amount	on signing of the loan agreement and inflow of minimum 30 % share of promoter's contribution
2nd instalment	30 % of loan amount	Inflow of additional 60% share of promoter's contribution and after delivery of all equipment at site
3rd instalment	30 % of loan amount	Inflow of minimum 90% share of promoter's contribution, on final installation of CST equipment at location
4th instalment	10 % of loan amount	On completion, commissioning, testing and inspection and utilization of 100% of the promoter's contribution

Source: https://www.ireda.in/images/HTMLfiles/8_Loan%20Scheme.pdf

Note: Main loan and bridge loan will be disbursed proportionately as indicated in the table above.

Considering the conditions determining suitability of thermal storage, the suitability of thermal storage in abandoned Indian mines have been analyzed in detail in Section 27.

9. Gravity Storage - As Repurposing option

9.1. Introduction to repurposing option

Gravity storage is a concept of storing energy in mechanical form and utilizing the potential energy to generate electricity with the help of gravity. The most common form of gravity battery is pumping storage hydropower which is covered in the options discussed earlier in this report. Another form of a gravity battery is one in which we lower a mass, such as a block of concrete or containers filled with sand to generate electricity. There is another concept that utilizes the force of gravity for storing electricity in which the heavy train are moved up hill using the access electricity in the grid and later dropped downhill during the high demand period to generate electricity by regenerative braking.

There is one more technology which is called lifted weight storage (LWT) in which surplus energy is used to lift solid objects vertically, mostly on a pulley, which then lowered down during electricity demand to run the generator.

This option of energy storage has capacity to store energy for longer duration of time and the energy loss is very less as compared to other options for energy storage. Gravity sources are designed to be paired with renewable energy sources such as solar and wind which are intermittent in nature. It is envisaged that gravity storage option has lower lifetime cost as compared to chemical batteries and has fewer environmental implications.

Energy Vault is a Swiss company founded in 2017 that provides a full-service energy storage provider which offers a diverse technology portfolio of turnkey energy storage products for both short and long durations, delivering valuable grid scale energy storage solutions. The mechanism used by energy vault to generate electricity is very well depicted in this video. The technology is in the development stage as the system prototype demonstration in an operational environment has been planned by various companies.

9.2. Global best practices with examples

9.2.1. Repurposing of a coal mine with full scale gravity energy store in Czech Republic by Gravitricity

Gravitricity is a Scottish firm which specializes in energy storage plans to build a working demonstration project at Darkov deep mine in Czech Republic. It is envisaged that the facility will produce enough power to supply electricity to 16,000 homes. The Darkov mine in the Moravian-Silesian region of the Czech Republic, near the city of Karvina is 700 meters deep. Gravitricity plans to store energy by lowering and raising a single massive weight suspended in the Darkov mine shaft. In its process Gravitricity uses heavy weights of up to 12,000 tons suspended in a deep shaft by cables attached to winches[152]. When there is excess electricity in the grid, at that time the weight is winched to the top of the shaft ready to generate power. This weight can then be released, providing power.

Figure 41: Shaft hoisting system at Darkov deep coal mine

Source: https://www.heraldscotland.com/business_hq/23340609.edinburgh-energy-storage-firm-test-tech-czech-mine/

9.2.2. Repurposing of a gravel mine with rail-based gravity energy storage technology at Parahump, Nevada, USA by ARES Nevada

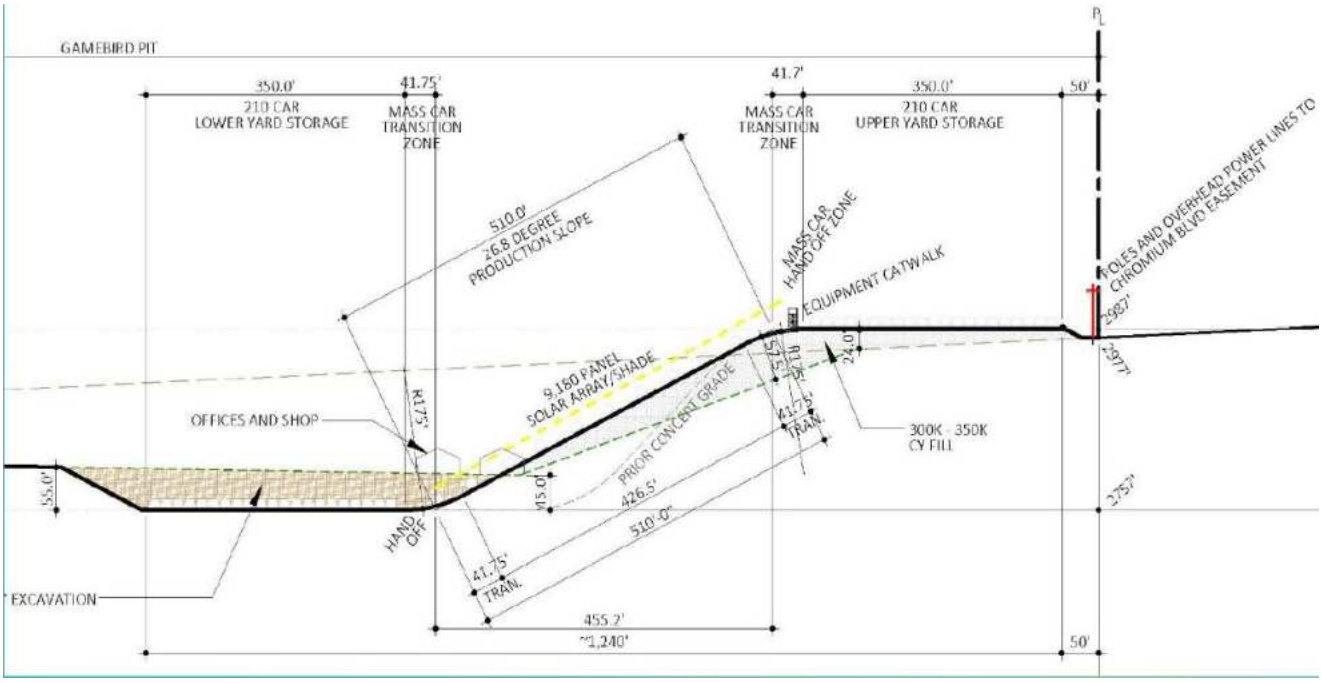
Advance rail energy storage (ARES) has announced to set up a rail-based energy storage solution at a gravel and sand mine. The 50 MW facility will be able to provide 15 minutes of regulation services at full capacity[153]. The facility will create approximately 30 direct jobs during construction. Below is the link to the presentation containing the details and the mechanism of the rail-based energy storage technology.

- Link

Figure 42: ARES Navada 50 mw project at gamebird pit

Source: https://www.sandia.gov/ess-ssl/wp-content/uploads/2021/LDES/Russ_Weed.pdf

Figure 43: Design scheme of ARES at Gamebird pit



Source: https://www.sandia.gov/ess-ssl/wp-content/uploads/2021/LDES/Russ_Weed.pdf

9.3. Working principle of technology

It is a method of storing energy by utilizing gravitational potential energy of an elevated mass which is lowered down to generate electricity. There are two mechanisms by which we utilize gravitational energy to store electricity which are explained below.

9.3.1. Weight raising

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 system can ramp up to its 4 MW power output in 2.9 seconds and can be developed with storage capacities ranging from 20 MWh to 80 MWh[154]. Energy vault is a company whose core product is a kinetic storage system that consists of multiple cranes and cement-like blocks as depicted in the picture given below. Similar technology can be used in underground mines that will lead to savings on the crane cost, but it will be restricted to the size of the shaft present in underground mines that will limit its capacity.

Figure 44: Energy vault system of piling blocks

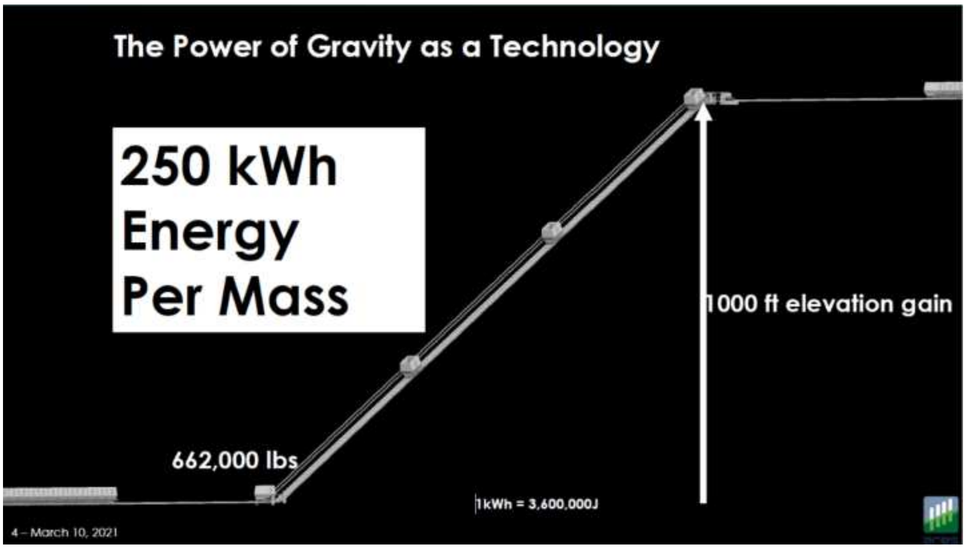
Source: https://darcypartners.com/research/gravity-powered-energy-storage-technologies

9.3.2. Advance rail energy storage

In this method a system of weighted rail cars that are towed up a hill of at least 200 feet to act as energy storage after which gravitational potential energy is used for power generation. Systems are composed of 5 MW tracks, with each car having a fixed motor to generate electricity. Installations can be scaled up to GW-level capacity by the addition of more tracks. Storage duration can be from 15 minutes to 10 hours with a response time of 3 seconds. Below is a link of the video that will help to better understand this concept[155].

- Link

Figure 45: Working principle of ARES

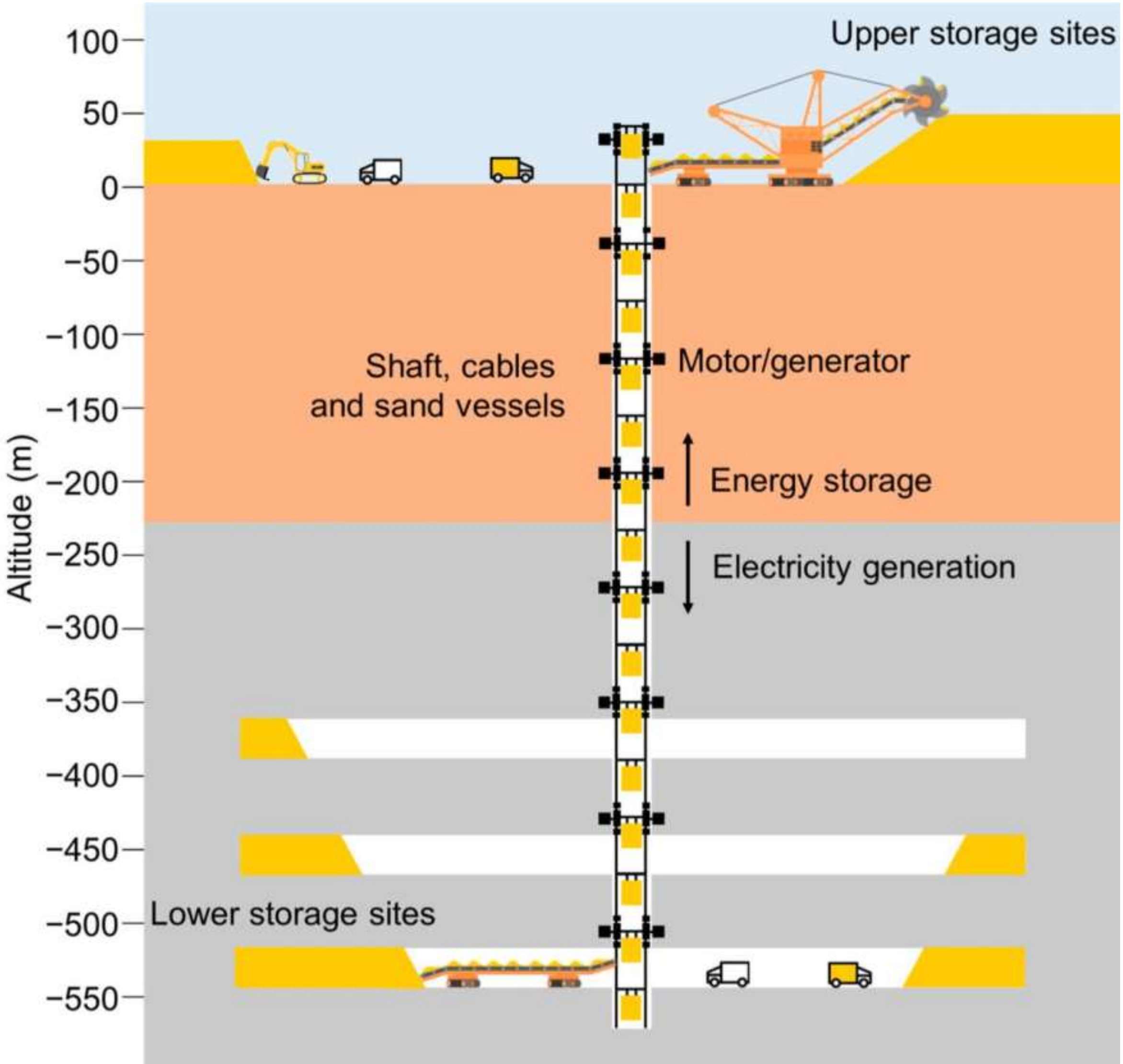


Source: https://www.sandia.gov/ess-ssl/wp-content/uploads/2021/LDES/Russ_Weed.pdf

9.3.3. Gravity energy storage in underground mines

This concept of energy generation has been designed for underground mines specifically using the preexisting infrastructure such as a mine shaft. In this concept the containers containing heavy material are lowered down to generate electricity via regenerative braking and then emptied below in a mine after which the emptied containers are brought up to the top using electricity which is again filled with the heavy material before lowering the filled container into the mine shaft. The main components of UGES are the shaft, motor/generator, upper and lower storage sites, and mining equipment[156]. The storage space available in a mine is directly proportional to the capacity of the energy storage system. The deeper and broader the mine shaft, the more power can be extracted from the plant. To maximize power capacity, the sand containers in the shaft occupy approximately 50% of the shaft's volume. The other 50% of space is required for filling and emptying the containers with sand. The figure below depicts the energy storage mechanism.

Figure 46: Energy storage in underground mine



Source: https://www.mdpi.com/1996-1073/16/2/825

Any heavy object that is present in abundance in the premises of the mines (preferably waste rock) can be used for filling the containers. The mining equipment is essential to managing the sand in the upper and lower storage sites. They consist of dump trucks, conveyor booms, bucket wheel excavators, and soil compactors. Dump trucks or conveyor belts transport the sand from the mine shaft to the storage sites and back.

9.4. Conditions determining suitability of technology

The following are the conditions that are required for a gravity energy storage system to work effectively in an underground mine.

- **Depth of the mine shaft** - An elevation difference is required between the upper storage site and lower storage site. For optimal performance, a height of at least 500 meters is recommended. Mines with a depth of at least 500 meters are preferable as they could theoretically store about 1.36 kWh of energy with a mass of 1,000 kg.

- **Diameter of mine shaft** – The wider a mine shaft is, the more will be the power generation capacity.
- **Mass of the object**– The object that is lifted and moved down should be high in mass to generate more electricity. Mass of the object moved is directly proportional to electricity produced.
- **Presence of heavy material nearby and its properties** – The material that is used as a weight for lowering and raising should be high in density and easily available within the mine itself to lower down the transportation and purchase cost of material. The material chosen should resist the typical conditions in mines such as moisture, pressure, and corrosive environments.
- **Storage volume present in mine** – The life of the project depends on the storage capacity of the mine. The higher the storage capacity, the more the life of the project.
- **Geotechnical factors and integrity of shaft** – Ground response to the falling of heavy weights should be observed and taken care of using dampers. The geological stability and integrity of the structure should also be surveyed on time to reduce any chances of failure within the shaft.

9.5. Potential for symbiosis with other repurposing options

This option of energy storage in underground mines can work in conjunction with the renewable's energy options, in which the electricity required to store the gravitational energy will be produced from the renewable sources of energy. The detailed analysis for this repurposing option has been done in section 26.

9.6. Potential environmental impact locally and GHG emission reduction potential

GES systems have a low environmental impact but may result into vibration in the nearby areas due to dropping down of weights that may create distress amongst the local population.

However, this technology uses clean source of electricity to operate generally and does not require burning of fossil fuels. The GHG emission reduction potential is equivalent to the amount of electricity produced during the demand time that may have been produced using conventional source of electricity generation like a coal based thermal power plant.

9.7. Employment effects

Gravity energy storage projects can generate employment opportunities at various stages as explained in the table below.

Table 26: Components of employment

Direct Employment	Indirect Employment
Site Preparation for installation	Hotels and lodges

Direct Employment	Indirect Employment
Geotechnical evaluation of the site	Restaurant
Electrical and mechanical installation such as turbines, generators, and control systems	General stores
Transportation of equipment, material and workmen	House help
System operators	Laundry & dry cleaning
Maintenance crew	Tea stalls and other small vendors
Safety and security crew	Local transporters
Administrative people	
Research & development specialist to continuously upgrade the system	

Source: PwC Analysis

Direct employment refers to jobs that are directly created by a specific business or industry. These are the jobs within the core operations of the company and are directly related to its primary activities. Indirect employment, on the other hand, refers to jobs that are not directly within the core operations of a business but are created as a result of the economic activity generated by that business or industry.

A 50 MW facility will be able to provide approximately 30 direct jobs during construction and 10 direct jobs during the operation phase[157].

9.8. Economic feasibility analysis

The technology is still in development phase and no such kind of data about the efficiency, output or input requirements of the system is available due to which the economic feasibility analysis may not be accurate and for that reason we haven't included it in our report.

As per international institute for applied systems analysis the investment costs of UGES are about 1 to 10 USD/kWh and power capacity costs of 2.000 USD/kW[158].

9.9. Pros and cons

Table 27:Pros and Cons of gravity storage

Pros	Cons
Long storage duration: Unlike chemical storage options, the gravity energy storage can hold the energy for long durations until any type of mechanical failure occurs which is very unlikely to happen.	**High initial investment:** The gravity energy storage setup requires high capital cost. However, they can offer long term savings.
Environment friendly: These systems are generally clean, use renewable source of energy for operation and do not emit greenhouse gas directly.	**Low efficiency:** The efficiency of energy conversion in these systems can vary, with losses due to friction, air resistance, and mechanical inefficiencies.
Low operational and maintenance cost: operational and maintenance cost of these systems are low.	**Topography:** These systems may not be practical or cost-effective in regions with limited elevation differences.

Pros	Cons
Enhanced grid stabilization: This system can generate electricity rapidly and helps in controlling the fluctuating demand of the grid, improving its reliability.	

Source: PwC Analysis

9.10. Suitability for India

Green Gravity, Australian renewable-energy generation company, plans to use weighted block and gravity to generate electricity in the Kolar Gold Fields (KGF) of Karnataka. A weighted block will be hauled when the renewable energy is present, and in absence of the renewable energy, weighted block will be released and will be pulled down due to gravity generating momentum to power the generator or turbine. The power generation is controlled by controlling the fall of the block though braking systems.

This technology can be set up in defuncted mines, ensuring no adverse environment affect, providing employment generation, and generating electricity when the renewable energy is not present.

Considering the conditions determining suitability of gravity storage, the suitability of gravity storage in abandoned Indian mines have been analyzed in detail in Section 27.

10. CO_2 Storage - As a Repurposing Option

10.1. Introduction to repurposing option

Carbon Capture and Storage (CCS) is one of the proposed options for minimizing global greenhouse gas emissions in the long-term. It involves capturing, compressing and injecting Carbon Dioxide (CO_2) deep underground. For deep underground storage sites, the options for CO_2 storage includes the following:

- **Unmineable coal seams** – These are the coal deposits that are unviable to mine. Injecting CO_2 into these coal seams can help enhance methane recovery (Coal Bed Methane, or CBM), while simultaneously storing the captured CO_2.
- **Deep saline aquifers** - Saline aquifers are vast underground formations of porous rock filled with brine water.
- **Depleted oil and gas reservoirs** – It's believed that these rock formations can potentially store high amounts of CO_2.

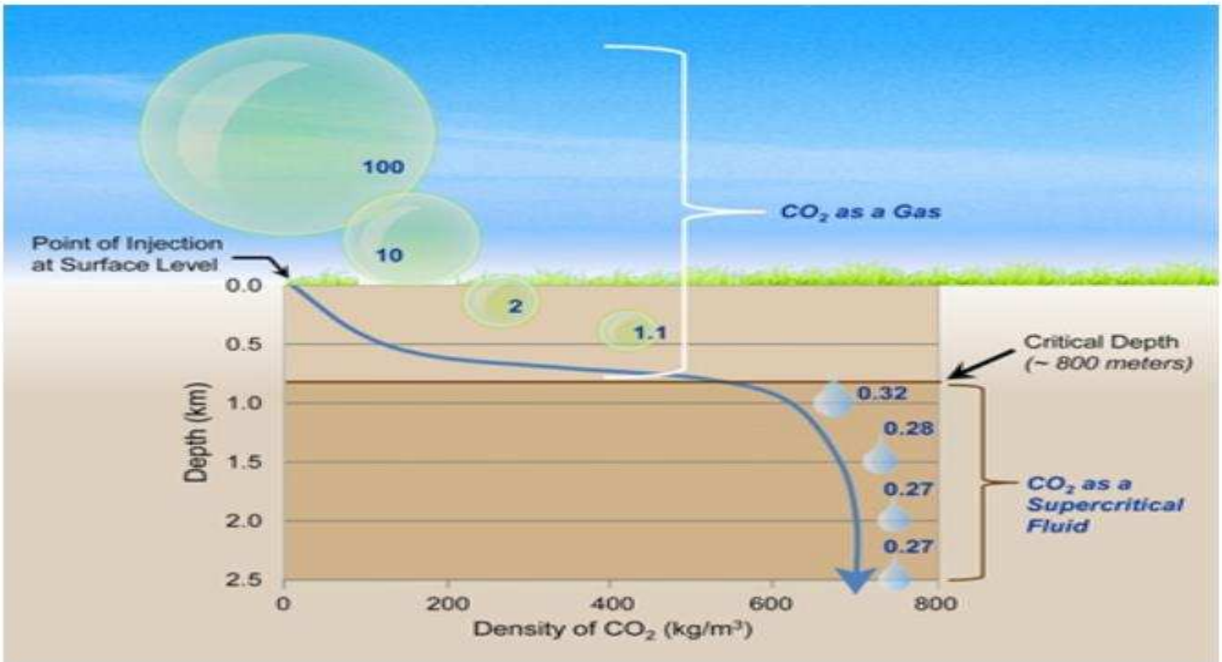
The storage must be such that it ensures safety, environmental sustainability, and cost-efficiency.

10.1.1. Storage of CO2 underground

CO_2 can be stored underground as a supercritical fluid. Supercritical CO_2 means that the CO_2 is at a temperature in excess of 31.1°C (88ºF) and a pressure in excess of 72.9 atm (about 1,057 psi); this temperature and pressure defines the critical point for CO_2. At such high temperatures and pressures, CO2 has some properties like a gas and some properties like a liquid. In particular, it is dense like a liquid but has viscosity like a gas. The main advantage of storing CO_2 in the supercritical condition is that the required storage volume is substantially less than if the CO_2 were at standard room pressure conditions[159].

The temperature and the pressure of the fluids within rock formations naturally rise. At depths below about 800 meters (about 2,600 feet), the natural temperature and fluid pressures are in excess of the critical point of CO_2 for most places on Earth[160]. This implies that CO_2 injected at this depth or deeper will continue to exist in a supercritical state due to the prevailing temperatures and pressures. The pressure effect on CO_2 is illustrated in the figure below.

Figure 47: volume of CO2 at each depth compared to a volume of 100 at the surface.



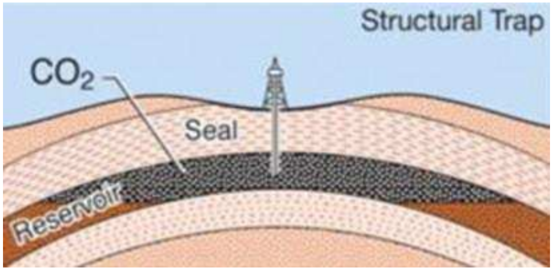
Source:https://netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-storage faqs#:~:text=Depth%20%E2%80%93%20The%20CO2%20storage,of%20CO2%20by%20volume

10.2. Trapping mechanism of CO_2 underground

There are four main mechanisms that trap the injected CO2 in the subsurface as explained below.

1. **Structural Trapping** - Structural trapping is the primary method of physically containing CO_2 within the rock formation, accounting for the most substantial CO_2 entrapment. In this process, the rock layers and faults within and above the storage formation, where CO_2 is introduced, act as barriers, preventing CO_2 from escaping the storage site. After injection, the supercritical CO_2 may exhibit greater buoyancy than other fluids within the porous rock, causing it to move upward through the rock's pores until it encounters and becomes trapped by an impermeable seal rock layer.

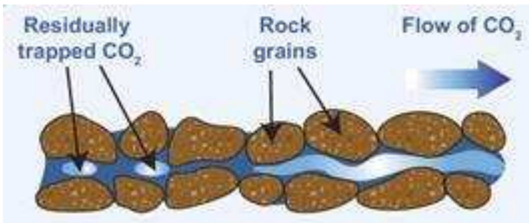
Figure 48: Structural trapping of CO2



Source:https://netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-storage faqs#:~:text=Depth%20%E2%80%93%20The%20

2. **Residual Trapping** - Residual trapping pertains to the CO_2 that remains confined in the spaces between rock grains as the CO_2 plume traverses through the rock. Upon injecting supercritical CO_2 into the formation, it displaces the pre-existing fluids as it makes its way through the porous rock. As the CO_2 continues its movement, small portions

Figure 49: Residual trapping of CO2

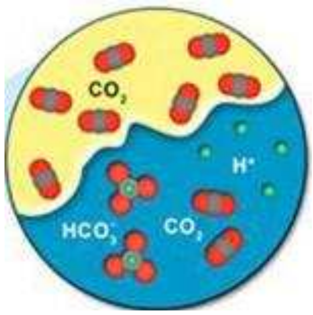


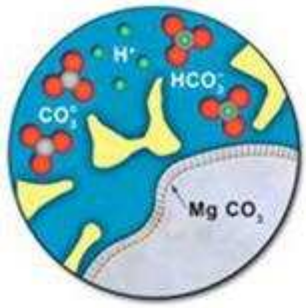
storage-faqs#:~:text=Depth%20%E2%80%93%20The%20CO2%20storage,of%20CO2%20by%20volume.

of it can be left behind as isolated, or residual, droplets within the pore spaces. These residual CO_2 droplets essentially become immobile, similar to water trapped in a sponge.

3. **Solubility Trapping** - In solubility trapping, a portion of the injected CO_2 dissolves into the brine water that is present in the pore spaces within the rock. At the CO_2 /brine water interface, some of the CO_2 molecules dissolve into the brine water within the rock's pore space. Some of that dissolved CO_2 then combines with available hydrogen atoms to form HCO_3 molecule[161].
4. **Mineral Trapping** - Mineral trapping is the term used to describe a chemical reaction that takes place when carbon dioxide (CO_2), which has dissolved in the brine water within rock formations, interacts with the minerals present in those rocks. As CO_2 dissolves in water, it initially creates a mild carbonic acid (H2CO_3), which subsequently transforms into bicarbonate (HCO_3). Over extended periods of time, this relatively weak acid can engage with the minerals within the adjacent rock, leading to the formation of stable carbonate

Figure 51: Solubility trapping of CO_2 *Figure 51:Mineral trapping of CO_2*





Source:https://netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-storage-faqs#:~:text=Depth%20%E2%80%93%20The%20CO2%20storage,of%20CO2%20by%20volume.

minerals. This process effectively traps and securely stores a portion of the injected CO2 within the geological formation[162].

The primary benefit of CO_2 *storage is that it reduces carbon dioxide emissions in the atmosphere thereby mitigating the impacts of climate change. There are also chances of capturing methane gas present in the coal seam by injecting carbon dioxide into the coal seam.*

So far, the technology readiness level of CCS is in varying stages of development, from early research through to full-scale commercial availability. Till now there is no project in which carbon is being captured in an underground coal mine and only one field test has been conducted for CO_2 storage in abandoned coal mines in Lagerio, Belgium. The technology is in development stage and more field tests are required for underground storage of CO_2[163].

10.3. Global best practices

Similar to depleted gas reservoirs and salt caverns, the concept of storing CO_2 in coal mines is influenced by projects involving the storage of natural gas in abandoned coal mines in USA. There are two other abandoned mine that were converted natural gas storage reservoirs, both located in the gassy Hainaut coalfield in southern Belgium as discussed below.

10.3.1. Leyden coal mine (USA)

The Leyden gas storage operation, initiated in 1961 near Denver, Colorado, USA. The Leyden Mine, which operated from 1903 to 1950, produced approximately 6 million tons of sub-bituminous coal during its existence. The mine comprised four shafts, offering access to two horizontal seams located between 240 and 260 meters below the surface in the upper cretaceous Laramie formation. In the late 1950s, the Public Service Company of Colorado (PSCo) began utilizing Leyden as a gas storage facility to optimize natural gas supplies. Originally intended to ensure gas availability in the Denver area during peak demand periods. Furthermore, it plays a crucial role in optimizing PSCo's gas buying and selling strategy throughout the year.

The cap rock consists of 20 m claystone in the Leyden Mine. The leak off test shows that the Leyden Mine's cap rock can only withstand 75% of the hydrostatic pressure which would be 1.8 MPa. During the initial development of the storage system, water was pumped from the mine as gas was being injected. Two active water wells were used to continuously remove approximately 50,000 m^3 of water from the mine each year. It was a room and pillar operation and PSCo reports that the extraction efficiency was about 35%. This means still 65% of the original coal remained in place after the mining ended, primarily in the pillars. The EPA (Environmental Protection Agency - USA) estimates that the sorption capacity of the coal within the mine ranges from 85 to 127 Mm^3 at the Leyden Mine facility's, average operating pressure of 1.1 MPa and from 100 to 140 Mm^3 at the facility's maximum operating pressure of 1.8 MPa.[164]

10.3.2. Anderlus and Peronnes Mines (Belgium)

The Anderlus and Peronnes Mines, located in the gassy Hainaut Coalfield in Southern Belgium (between Mons and Charleroi) have been used for seasonal storage of natural gas. Anderlus mine operated between 1857 and 1969. 25 MT of sub bituminous coal were produced during its operation. Storage operation began in 1980 at depths from 600 to 1100 m. The overburden is almost 50 m thick but varies from South to North. A thrust fault acts as a primary hydrogeological barrier (Piessens and Dusar, 2004a). The reservoir volume assumed to be 6 to 10 Mm^3 which could be considered to store 180 Mm^3 of CH_4. Peronnes Mine is also located in the same area and it was in operation from 1860 until 1969. This mine could store 120 Mm^3 of CH_4.[165]

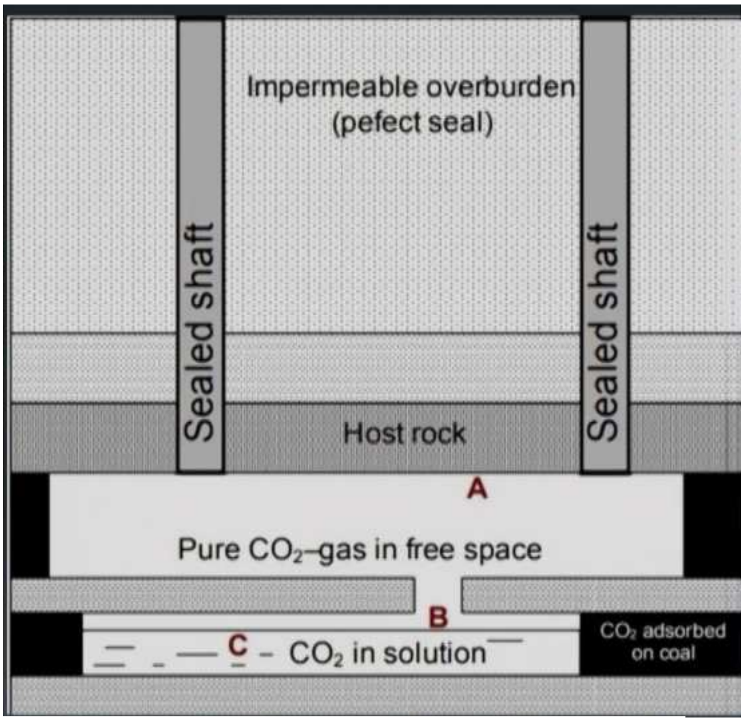
10.4. Working principle of technology

CO_2 storage is broadly divided into two parts. CO_2 storage in abandoned coal mines and CO_2 storage in deep unmineable coal seams. There are a lot of methods to store CO_2 in abandoned coal mines like free space, adsorption on coal and mine water. The frequency of field tests conducted on abandoned coal mines is a lot less than deep unmineable coal seams in which two methods have been identified for CO_2 storage which are enhanced coalbed methane recovery and CO_2 underground coal gasification.

10.4.1. CO_2 storage in abandoned coal mines

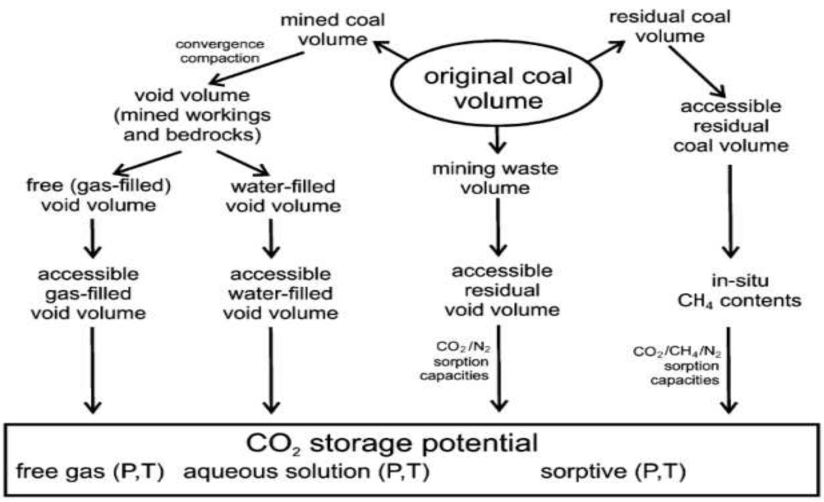
Carbon dioxide (CO_2) can be sequestered in an abandoned coal mine through three physical mechanisms: adsorption on the remaining coal, dissolution in the mine water, and compression in the vacant space within the mine. The adsorption of CO_2 onto coal is influenced by van der Waals forces between the adsorbate (CH_4 or CO_2) and the adsorbent (coal). This process is contingent on the coal type and the available quantity of coal for adsorption. Accurately determining the coal's adsorption capacity is crucial, as a significant portion of CO_2 is expected to be adsorbed through this mechanism. CO_2 is also expected to

Figure 52: Conceptual diagram for storing CO2 in abandoned coal mine



Source: Lutynski & Sakiewicz

Figure 53: Storage potential of CO2 in underground



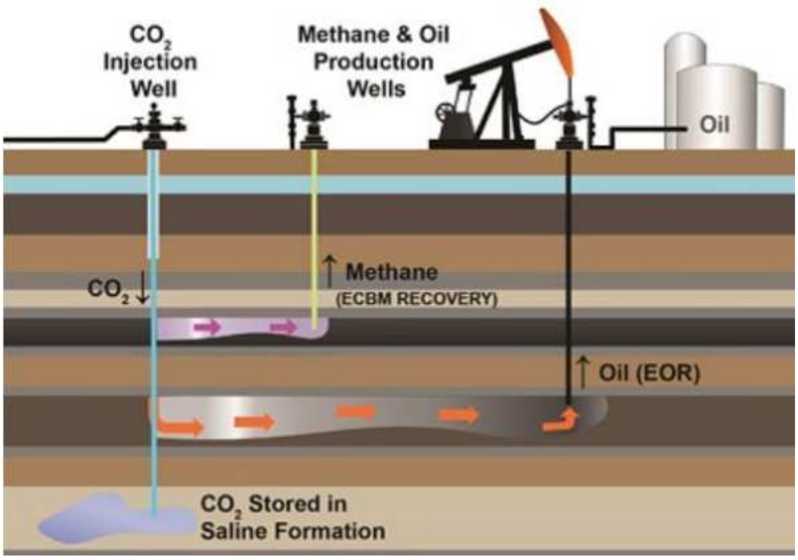
Source: https://www.researchgate.net/publication/288828348_Carbon_Dioxide_Storage_in_Abandoned_Coal_Mines dissolve in ground water which has the less contribution amount compared to the other modes of storage (in most cases, less than 10% of the total sequestration amount).166

The amount of storage for each mechanism varies from mine to mine depending on coal properties and the mine pressure. CO_2 absorbs on coal more than CH_4 (almost twice). By injecting CO_2 into the abandoned coal mine CH_4 may be released which can offset some of the cost of CO_2 sequestration.[167]

10.4.2. CO_2 storage in unmineable coal seams

Coal that is considered unmineable because of geologic, technological, and economic factors (typically too deep, too thin, or lacking the internal continuity to be economically mined) may still serve as locations to store CO_2. To be considered for CO_2 storage, the ideal coal seam must have sufficient permeability and be considered unmineable. Coal seams may also contain methane (CH_4), which can be produced in conjunction with CO_2 injection in a process called enhanced coal bed methane (ECBM) recovery as depicted in the figure below. In coal seams, the injected CO_2 can be chemically trapped by being adsorbed (or adhered) to the surface of the coal while CH_4 is released and produced. This trapping mechanism allows for permanent storage of CO_2. Diagram depicting ECBM and EOR recovery process by which CO_2 is injected and used to drive the natural gas or oil towards a recovery well.[168]

Figure 54: ECBM and EOR recovery process



Source :https://netl.doe.gov/carbon-management/carbon-storage/faqs/carbon-storage-faqs

10.5. Conditions determining suitability of technology

There are various factors that determine the suitability of CO_2 storage in underground mines. Let us first have a look at the basic conditions for gas storage in abandoned mines introduced by Houtrelle. S. Houtrelle in 1999 in his Maser Thesis 'Stockage de gaz naturel en mine de charbon abandonnée. Approche géologique du site d'Anderlues' introduced some basic conditions to store gas in abandoned mines.

- There should be no lateral communication with other mines. This would allow the gas to migrate to places where it becomes difficult to retrieve.
- There should be no communication between the mine reservoir and the surface. This would allow the gas to leak to the atmosphere.
- The amount of the influx of water into the mine should preferably be low. The mine has to be kept dry by pumping for storage of CO_2 to prevent gas pressures which may cause leakage of the gas.

Two suggested criteria's for CO_2 sequestration in abandoned coal mines are:

- The top of the mine working should be atleast 500m underground.
- The reservoir pressure should be 30% more than hydrostatic pressure to prevent water influx[169].

Some other key factors are as follows:

1. **Effective storage capacity** - The underground mine must have suitable geological formations that can securely and effectively trap CO_2. This involves assessing the presence of faults, fractures, or other potential pathways that could compromise the containment of CO_2.
2. **Ease of transportation** – The feasibility of CO_2 storage is influenced by transportation cost. The closer the CO_2 capture site to the storage site the better it is.
3. **Storage site characteristics** - It is necessary to understand the geological and hydrogeological conditions of the storage site. This involves geotechnical assessment, seismic studies, and other techniques to assess the suitability of the underground formations.

10.6. Potential for symbiosis with other repurposing options

This option can be clubbed with renewable energy repurposing options in order to utilize the electricity generated to power the injection wells. The detailed analysis for this option has been done in section 26.

10.7. Potential environmental impact locally and GHG emission reduction potential

CO_2 storage directly removes CO_2 from the atmosphere that was set to be released in the atmosphere. But it has some environmental impact in the area nearby and the same has been described below.

1. There is a potential for ground water contamination due to injection of CO_2.
2. The transportation of the captured carbon to the storage site may lead to addition of GHG in the environment that may affect the local area.
3. The area surrounding abandoned mines may have developed its own ecosystem. CO_2 injection and storage activities could disrupt local flora and fauna.

In a world heavily reliant on fossil fuels, carbon dioxide (CO_2) capture and geological storage (CCS) emerges as a highly promising technology for curbing greenhouse gas emissions and addressing climate change. If fully implemented, CCS may contribute to reduce 20% of global emissions from fossil fuels by 2050 and 55% by the end of this century[170]. The entire Carbon Capture and Storage (CCS) process involves capturing CO_2 from significant stationary sources like coal-fired power plants and heavy industries. Subsequently, the captured CO_2 is transported and stored in suitable geological settings. This process effectively returns carbon, emitted in the form of CO_2 from fossil fuels, back to geological sinks. GHG emission reduction potential depends on the following factors.

1. The amount of CO_2 captured is directly proportional to capturing efficiency and source of CO_2 capture such as power plants, industrial facilities, or natural gas processing plants.
2. The potential for GHG emission reduction is dependent on the availability of suitable storage sites with sufficient capacity to store captured CO_2.
3. The success of GHG emission reduction through CO_2 storage relies on preventing CO_2 leakage from storage sites otherwise the stored CO_2 may leak into the atmosphere that will fail the purpose to store CO_2 in first place.

10.8. Employment effects

The development and operation of CO2 storage facilities in underground coal mines require a diverse workforce as given in the table below.

Table 28: Components of employment

Direct Employment	Indirect Employment
Site Preparation for installation	Hotels and lodges
Geotechnical evaluation of the site	Restaurant
Electrical and mechanical installation such as CO_2 injection system	General stores
Transportation of equipment, captured CO_2 and workmen	House help
System operators	Laundry & dry cleaning
Maintenance crew	Tea stalls and other small vendors
Safety and security crew	Local transporters
Administrative people	
Research & development specialist to continuously upgrade the system	
People involved in regulatory and compliance work	

Source: PwC Analysis

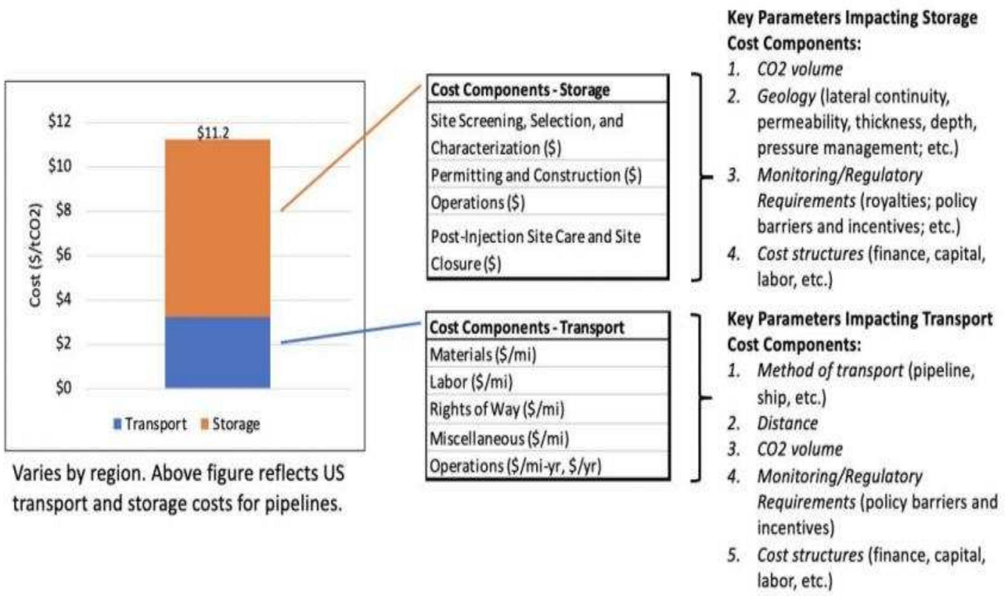
10.9. Economic feasibility analysis

The total cost of carbon capture and storage consists of the costs of:

- CO_2 capture at the emission source – purifying CO_2 from a gas stream up to over 95% purity by volume.
- CO_2 dehydration and compression/liquefaction, depending on the transport method.
- CO_2 is transported by pipeline, ship or mobile vehicle.
- CO_2 injection and monitoring and verification of stored CO_2.

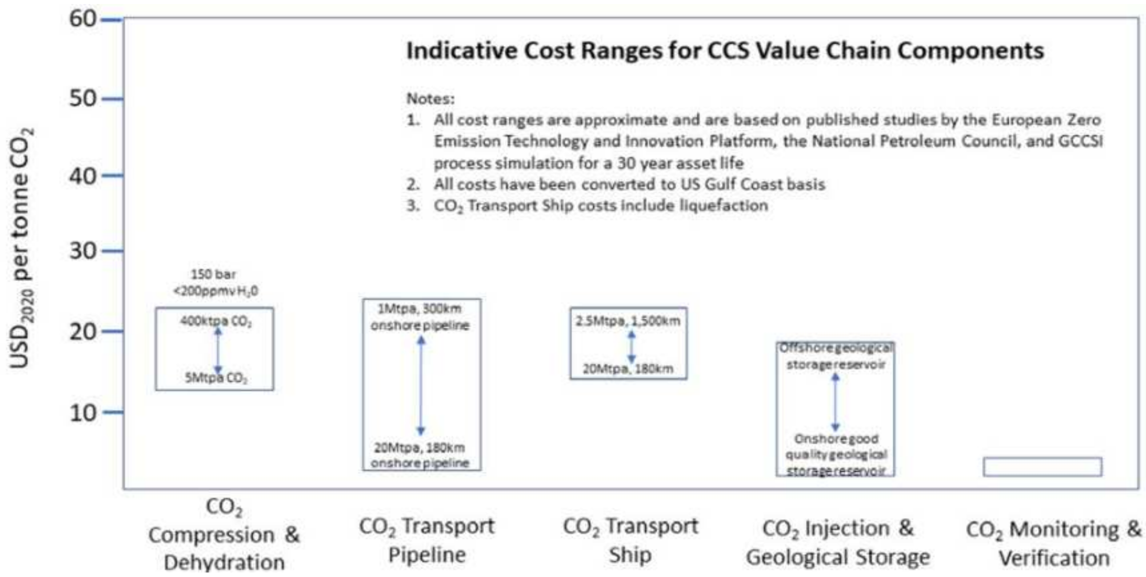
The cost of each CCS component varies from project to project, primarily due to differences in the size and location of the CCS facility and the characteristics of the CO_2 source. Technology is a vital consideration in CCS, but it is not the only factor. A range of other factors feed into costs across the CCS value chain.

Figure 55:Summary of CO_2 Transport and Storage Cost Components and Parameters



Source - https://globalchange.mit.edu/sites/default/files/Smith-TPP-2021.pdf

Figure 56:Indicative Cost Ranges for CCS Value Chain Components (excluding capture) – US Gulf Coast



Source- https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf

Table 29: Capital cost requirement of CCS technology

Total Capital Requirement	
Bare Erected Cost (BEC)	Process equipment
	Installation
	Supporting facilities
	Direct and indirect labor
Engineering Procurement and Construction (EPC)	0.15 BEC
Process Contingency	0.159 (BEC + EPC)
Project Contingency	0.207 (BEC + EPC + Process Contingency)
Total Plant Cost (TPC)	**Sum of the above**
Start-up costs	6 months operating labor • 1 month maintenance materials • 1 month chemical and consumables • 1 month waste disposal • 25% of one month fuel cost • 2% TPC
Inventory Capital	TPC + Owner's costs
Financing cost	2.7% TPC
Other Owners' costs	15% TPC
Owner's Cost	**Sum of the below**
Total Overnight Cost (TOC)	TPC + Owner's costs
Distribution of TOC over the Capital Expenditure (before escalation)	10%, 60%, 30%, in 3-year period
Escalation Multiplier (dependent on CRF)	1.16 (base case)
Total As-Spent Capital (TASC)	Escalation multiplier X TOC

Source: https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf#page=43&zoom=100,0,0

Table 30: Fixed operating cost of CCS technology

Fixed Operating Cost	
Maintenance costs	2.2% of TPC/year
Maintenance labor	40% of maintenance costs
Maintenance materials	60% of maintenance costs
Operating labor cost	USD 75,000/person-year

Fixed Operating Cost	
Number of operators	3 (base case)
Number of shifts	5
Administrative/support labor	30% operating labor + 12% of maintenance cost
Insurance cost	0.5% TPC
Local taxes and fees	0.5% TPC

Source:https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf#page=43&zoom=100,0,0

Table 31: Variable operating cost of CCS technology

Variable Operating Cost	
Raw process water	USD 2/cubic meter
Activated carbon	USD 2.2/kg
Diatomaceous Earth	USD 2.75/kg
MEA amine	USD 2/kg
Corrosion Inhibitor	20% of MEA cost
Soda ash	USD 0.68/kg
Special waste	USD 88.2/ton
Special waste disposal costs (nonhazardous)	USD 2.7/cubic meter
Sewage cost	

Source:https://www.globalccsinstitute.com/wp-content/uploads/2021/03/Technology-Readiness-and-Costs-for-CCS-2021-1.pdf#page=43&zoom=100,0,0

10.10. Pros and cons

Table 32: Pros and Cons of CO_2 storage

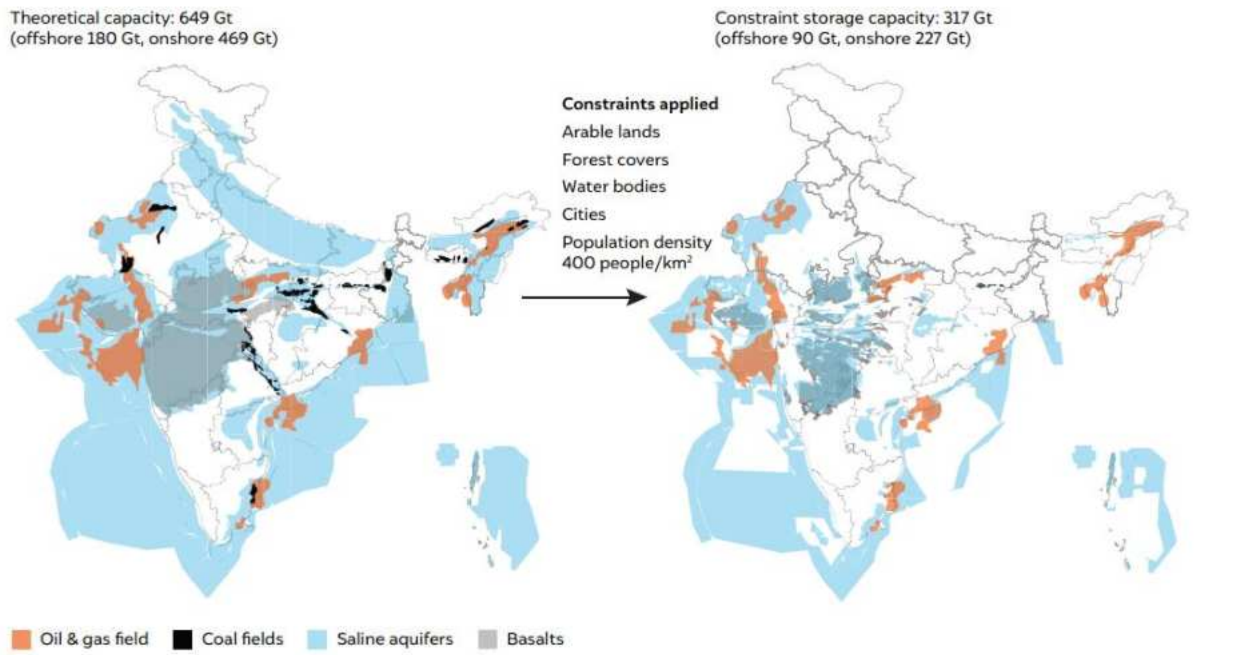
Pros	Cons
High storage capacity: Underground mines have vast storage capacity and can be used store large amount of CO_2.	**Depth for storage:** CO_2 storage can be deployed in deep mines with depth greater than 800m as CO_2 adsorption increases with depth. In India most of the underground mines are not so deep.
GHG reduction: In this storage system we are directly capturing the CO_2 from its source before it is being released in the air.	**Leakage potential:** There are chances of leakage of stored CO_2 from underground mines due to fractures or geotechnical failures owing to the years of mining operations.

Pros	Cons
Reduced capital cost : Repurposing a coal mine leverages existing infrastructure, such as tunnels and shafts, potentially reducing the costs associated with establishing new storage sites.	**Ground water contamination:** Injection of CO_2 into abandoned mines may pose risks of water contamination which may lead to ground water contamination if the same water goes back into the water table.
Employment potential: Establishing CO_2 storage can create new economic opportunities for the local community, providing jobs and potentially revitalizing the region.	
Methane recovery: There is a potential for methane recovery from the unmined coal seams based on the adsorption of coal.	

Source: PwC Analysis

10.11. Suitability for India

Figure 57: Challenges that could significantly reduce the area available for CO_2 storage



Source : https://www.ceew.in/sites/default/files/how-can-india-boost-carbon-storage-sequestration-potential-ccus-projects.pdf

India emitted 2.95 GT of CO2 in 2018, which is expected to rise with continued growth (GHG Platform India 2022). With regard to CCS deployment, India is still in the nascent stages compared to forerunners such as the United States, Norway, and China. Studies show that almost 5 to 10 GT CO2 must be cumulatively sequestered in India by 2050 to meet the 2°C carbon budget171.

India has a huge coal resource of about 293.5 billion tons with a CBM resource of almost 2,600 billion cubic meters (BCM) (MoPNG 2022). Studies indicate that 3 Mt CO2 can be sequestered for every BCM of CBM extracted. Coal resources below 300 m cannot be extracted through the conventional mining process, making them uneconomical. These resources should be targeted for ECBMR instead. About 57 per cent and 38.9 per cent of methane can be recovered through ECBMR at a depth higher than 300 m for bituminous coal and lignite, respectively. These uneconomical coals could be the prime targets for CO2 storage.[172]

Table 33: State wise CBM resources and CO_2 storage potential

State	Estimated CBM Resources (bcm)	CO_2 storage potential (Gt)
Jharkhand	722.08	1.23
Rajasthan	359.62	0.42
Gujarat	351.13	0.41
Orissa	243.52	0.42
Chhattisgarh	240.69	0.41
Madhya Pradesh	218.04	0.37
West Bengal	218.04	0.37
Tamil Nadu	104.77	0.12
Andhra Pradesh	99.11	0.17
Maharashtra	33.98	0.06
Northeast	8.50	0.01
Total	**2,599.48**	**4.00**

Source: https://www.ceew.in/sites/default/files/how-can-india-boost-carbon-storage-sequestration-potential-ccus-projects.pdf

Considering the conditions determining suitability of thermal storage, the suitability of thermal storage in abandoned Indian mines have been analyzed in detail in Section 27.

11. Wind Power on Mining Land - As a Repurposing Option

11.1. Introduction to repurposing option

Wind energy is one of the renewable sources of energy which just like solar energy is free and inexhaustible natural resource and a source of clean, non-polluting electricity. With the cost of energy generation from the wind turbines going down it is getting popular among the countries. India with 302 GW of wind potential at 100m height[173], needs different options to utilise this potential and move towards clean and green energy. This will not only help India to transit towards clean energy but also to achieve its targets of net zero carbon. The Abandoned Mine Lands (AML) can serve as an excellent location for the wind farms.

India with a vast geography has good conditions for the wind farms, also the AML are in the states like Andhra Pradesh, Maharashtra, Orissa, Tamil Nadu with conditions that matches the requirement of feasible wind farm. There three reasons to which AML favours to develop a wind farm:

- A wind farm (can comprise of 5-150 windmills) requires consistent and sufficient supply of wind, as the mines are generally on the hilly area and are widely open, so they can easily serve this purpose.
- Also, to have a feasible wind farm, the projects require access to large and open sites which AML's can provide easily.
- One more advantageous situation which AML can provide is the availability of existing infrastructure including roads and power transmission lines, which can help reducing the project cost.
- The permanent direct impact area of wind farm varies mostly beneath 0.4 hectare per MW, which includes all the physical structure installed.[174]

Wind power in India has seen growth in past many years and with the decrease in the cost of generating electricity and positive regulatory support from the government the wind power has become one of the major renewable energy resources.

Currently a total of 43.77 GW of wind energy has been installed in India as of 30 June 2023, which will be expanded further to 99.89 GW by the end of year 2029-30[175]. And to facilitate the power transmission, Government is constructing a total of 10,750 km intra-state transmission lines and 27500 MVA sub-stations under the Intra-State GEC Phase-II (InSTS GEC-II) scheme[176]. It is noteworthy that 1,12,250 MW is the current Inter State transmission capacity. The total inter-regional transmission capacity is anticipated to be around 1,50,000 MW in 2030 with the new inter-regional transmission lines now being implemented or planned.[177]

Additionally, there have been many regulatory upgradations made by the Government of India to attract investors and renewable energy developers to invest more into wind power, like:

- Government of India extended the waiver of Interstate transmission system ISTS charges on transmission of electricity generated from solar and wind sources for projects that were to be commissioned up to 30th June 2025[178]
- Technical Support including the wind resource assessment to identify the potential sites is being provided by the National Institute of Wind Energy - Chennai
- Several fiscal and financial incentives such as Accelerated Depreciation benefit; concessional custom duty exemption on certain components of wind electric generators, are also provided to the wind power developers.

11.2. Global best practices with examples

Globally, there are some examples of repurposing the abandoned mine lands into wind power installations. Countries like Germany, United States, and Ireland have already repurposed some of their mine lands and installed a complete wind farms which are now supplying energy to the nearby areas. Some of the case studies have been summarized as follows:

11.2.1. The Buffalo Mountain Wind Farm[179]

It was in 2000, when the Anderson County in Tennessee officially started the wind farm which was established on a former strip mine site on Buffalo Mountain. This wind farm had three turbines with 660 kW capacity and generated 4000 MW hours of electricity annually which is enough to power approximately 400 homes. The Buffalo Mountain wind farm went through an expansion in 2004 and produced electricity enough for around 4000 homes.

The Tennessee Valley Authority (TVA), a federal Corporation and the Public Power Company approach the about the possibility people using the mind into a wind farm. The Mining Company saw it as an opportunity to explore, use it innovatively and generate some revenue from the waste property. 180The Mining Company then installed 3 turbines on Buffalo Mountain in 2000 and supplied power to the nearby residential buildings and business customers. The company added 15 more turbines in 2004 and the TVA is now purchasing the energy generated from new turbines as a part of the PPA made with the turbine Developers.

Figure 58: Wind farm at buffalo mountain mine site

Source: https://semspub.epa.gov/work/HQ/176038.pdf

11.2.2. Glenrock Wind Farm[181]

The Dave Johnston coal mine opened the wind farm in December 2008. This coal mine started its operation in 1958 and the operations seized in 1999. The reclamation work was completed in 2005 and towards the end of reclamation work the company determined to set up the wind projects on this waste land.

Figure 59: Glenrock wind farm

Source: Pacificorp

This area had an excellent wind resource, and the company already owned the land also the mine land had access to existing transmission facilities, the Rocky Mountain power, and so three wind power projects were constructed on approximately 47000 acres of land. These three wind power projects had a combined generating capability of 237 megawatts and consisted of 158, 1.5 megawatt turbines spread across the three projects.

This much amount of electricity is sufficient to supply energy to about 66000 homes annually. This project not only changed the view of the land and provided renewable energy but also give employment to about 300 workers during the construction phase and around 15 workers during the operation phase. The Rocky Mountain power is also working with the local colleges and Educational Institutes to expand the educational opportunities energy Technology.

This project was the result of combined efforts from the corporate commitment, positive regulatory interaction and dedicated workforce. All the teams work in a direction minimise the environmental impacts while reclaiming the land which included avoiding unnecessary land disturbances, erosion, providing sufficient drainage control and other works.

11.2.3. Somerset Wind Farm[182]

Somerset wind farm generates 25000 MWh of electricity annually which is enough to supply energy to 3000 homes. The foundations of this wind farm were laid in October 2001 with only six, 5 MW turbines which were increased with time. The Somerset wind farm location was chosen due to both adequate wind resources and the presence of infrastructure. Roads and electricity transmission cables were already in place due to previous mining activities, which decreased the project expenses.

Additional investigation and remediation were needed because of the previous mining operations at the site to make sure the surface could handle the weight of the six wind turbines. Under each turbine location, 16-foot perimeter holes were dug, and 15-ton weights (about equivalent to the weight of the turbines) were then placed to check for any structural flaws. For the foundations of each of the turbines, 180 to 200 cubic yards of concrete and 23,000 to 26,000 pounds of reinforced steel were combined.

Figure 60: Somerset wind farm

Source: https://semspub.epa.gov/work/HQ/176038.pdf

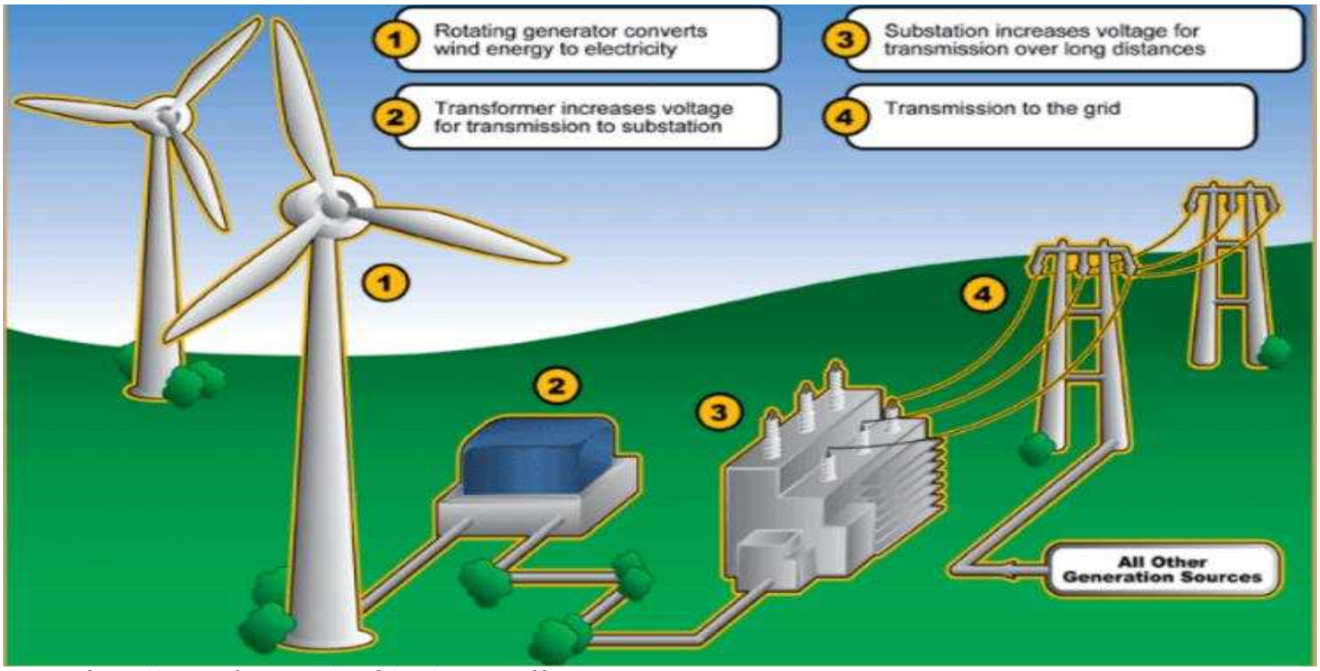
Additionally, Somerset Windpower LLC created plans to handle on-site circumstances. One wind farm, for instance, was built on terrain that had once been deep mined, which would have compromised the stability of the foundation. Before pouring concrete into the shaft to stabilize the structure, the turbine's base was centred over the mine's stable main heading corridor. To further identify subsidence that would jeopardize the turbine's base, a tilt sensor was mounted on the turbine. The Somerset wind farm has demonstrated that the strength of the wind can successfully provide clean, usable energy with careful planning, in-depth site analysis, innovative building techniques, and good corporate and community partnerships.

Link for one more case study for a wind farm on a AML is:
https://www.lifesizemedia.com/uploads/oakdale_brochure.pdf

11.3. Working principle of technology

The mine land is resurfaced to make it appropriate for installing the wind turbines. After resurfacing the land and doing the technical feasibility test, the wind turbines, transformers, substations, and main transmission lines are installed. The electricity is generated by the generators present in the housing on turbines. These generators get their motion from the rotating turbines, which are rotated by the force of wind. Transformers Step Up the electricity produced by the generators into transmittable voltage, this high voltage electricity is then sent to the grid via substation.

Figure 61: Working principle of wind energy generation.



Source : https://semspub.epa.gov/work/HQ/176038.pdf

11.4. Conditions determining suitability of technology

The specific conditions required for the repurposed wind power technology to function effectively and sustainability[183]. A successful wind energy site must have these five major qualities[184]:

- Typically, the wind technology location would be on a hill or in an open area without any adjacent obstacles. The tops of smooth, rounded hills, water, broad plains, and wind-driven mountain gaps are all desirable locations.
- Sufficient distance from neighbours who are sensitive to noise. Even though modern wind turbines are incredibly quiet, very strict maximum noise levels must be fulfilled in order to receive planning approval.
- Reliable grid connection - All of the wind turbines we sell must be connected to an appropriate three-phase electrical source, and the bigger multi-MW turbines may be grid-connected to 33 kV power lines.
- Feasible site access - Due to the size and weight of wind turbines, the access roads and tracks to the site must be strong enough to carry big loads without having any weak bridges, overly sharp turns, or high incline.

- For small wind turbines, the yearly average wind speed should be at least 9 mph, or 4 m/s, and for utility-scale turbines, it should be at least 13 mph, or 5.8 m/s[185].

However, there might be some on sight checking of the conditions to determine whether the land is suitable for installation of the wind farm or not. Like - Additional investigation and remediation were needed at the Somerset wind farm site because of previous mining operations there in order to make sure that the surface was structurally sound enough to handle the weight of the six wind turbines. Under each turbine site, 16-foot perimeter holes were dug, and 15-ton weights (about the size of the weight of the turbines) were then inserted into the holes to identify any structural weaknesses[186].

11.5. Potential for symbiosis with other repurposing options

Table 34: Potential symbiosis with wind power

Repurposing options	Degree to which options can be combined
PV on mining land	A pilot test has been carried out in Breña wind farm, on one of the wind turbines that is owned by ACCIONA. On the wind turbine they have set up 120 solar panels that are installed in fifty meters of height on the tower, with a power of 9.36 kilowatts peak. To optimize the capture of solar energy, the panels have been integrated with a southeast-southwest orientation. Organic solar panels are being used that are barely one millimeter thick, and use carbon as raw material, offering lightness and great structural flexibility, and are recyclable. These panels also have low maintenance costs[187]. In the US, during winter the wind is strong and comparatively less sunlight is available whereas in summer the wind speeds are low, and the sun shines brighter for a long duration. Since the peak operating time for wind and solar systems are different and mostly opposite, hybrid systems ensure that energy is provided whenever there is a need[188].
Horticulture	Be it undertaking horticulture in open cast mine, or vertical farming in underground mine, both have some sort of power requirement. Wind turbines will be able to meet the requirement and the excess can be synced with the grid. This will make the farm self-reliant for its power requirement.
Pumped Storage Hydropower	The idea is to utilize the surplus wind power during nighttime to pump water from lower reservoir to upper reservoir and during daytime when the power demand is high, then the power is produced by flowing the water downwards to fulfill the power demand[189].
Thermal Energy storage	A thermal energy storage system mainly consists of three parts, the storage medium, heat transfer mechanism and containment system. The thermal energy storage system modeled uses two-tank-direct configuration where the heat transfer fluid (HTF) also acts as the energy storage medium. It requires two separate tanks, eliminating the need of a heat exchanger to transfer heat from the collected HTF to the storage medium. The fluid gets stored at its lower temperature in a cold tank, and is heated by mechanical work from wind turbine, and then gets stored in the hot tank at an elevated temperature. The energy stored in the hot tank is delivered to the load by pumping the HTF through the boiler. It is assumed that saturated liquid water is fed to the boiler, and it exits as saturated steam. Here, the HTF cools down in the exchanger and is pumped back to the cold tank. The output power is represented by the flow rate of the saturated steam generated in the boiler[190].
Compressed Air Energy Storage	The major challenge of wind energy while integrating into the electrical grid is that the resource is intermittent and unpredictable. With an energy storage system integrated with wind turbine, surplus energy can be stored and then regenerated when demand is higher. With CAES system energy is stored prior to

Repurposing options	Degree to which options can be combined
	electricity generation, eliminating the need and losses associated with generating electricity twice[191].

Source: PwC Analysis

Wind power generation options can be optimally combined with solar generation options (such as solar PV) under wind-solar hybrid project mechanism. Several such projects have come up globally where wind and solar assets have been co-located for optimized generation. Apart from that horticulture can also co-exist in a wind power farm in the unutilized area.

11.6. Potential environmental impact locally and GHG emission reduction potential

Some of the major climate and environmental impacts of the repurposed wind technology have been summarized as follows[192]:

- Cleaning up abandoned properties may involve tearing down or repairing structures to keep them from turning into "attractive nuisances." Source contamination is also eliminated from a site as tailing piles are taken out to make room for reuse. Local ecosystems can be rebuilt once a site has been cleaned up.
- Criteria pollutants and greenhouse gases, which are the main causes of global warming, are not released by wind energy installations.
- Cleaning up tailings heaps to prepare a location for a wind farm can help avoid polluting drinking water supplies. Aquatic habitats are shielded from the effects of contaminants by riverbank clean-up.

The Oakdale Colliery wind power project is projected to reduce carbon emissions by 4,400 tonnes annually. At the 400-acre location, it is a 4MW project[193].

11.7. Employment effects

A wind farm is expected to result in considerable incremental property tax revenue for the state and create about 15-20 full-time permanent jobs for a 100-200 MW wind farm.

At the height of wind farm construction, more than 300 people are employed in temporary construction jobs. Additionally, in the case of the Rocky Mountain Power also worked with local institutions to expand educational opportunities in wind energy technology194.

11.8. Economic feasibility analysis

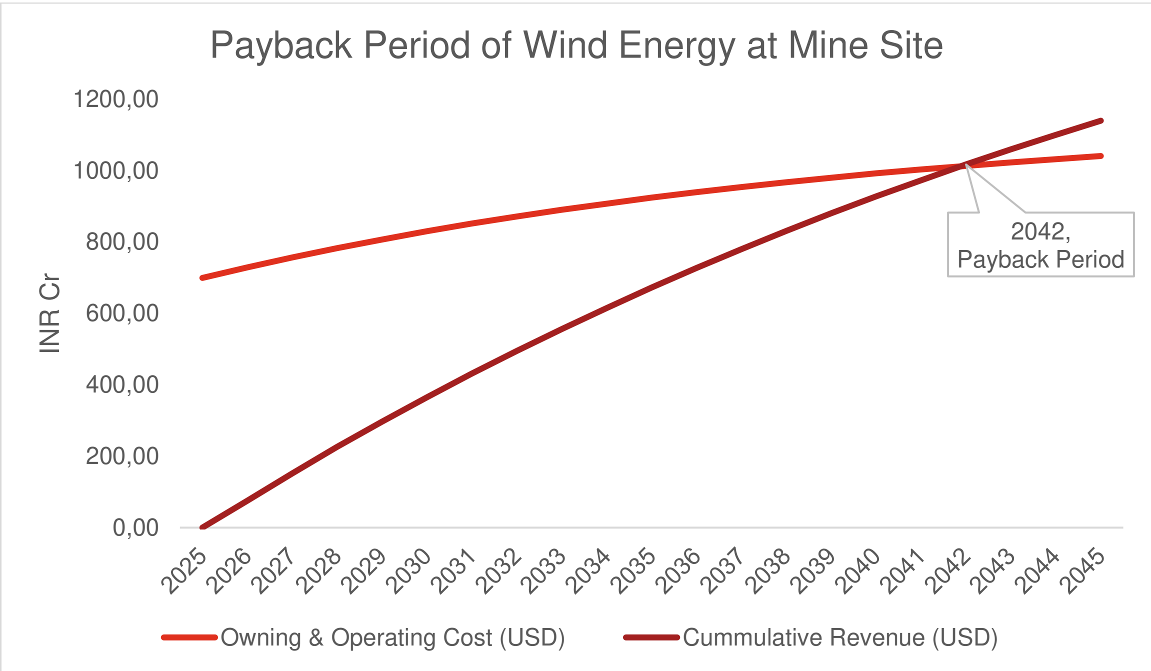
It is noteworthy that a 2 MW (small) windmill is typically 80-90 meters tall, whereas as large windmills (12 MW) can be up to 200 m in height. On average, a wind energy farm requires around 0.6 hectares of land per MW (permanent and temporary) of installed capacity. Additionally, it costs up to INR 6-8 crores / MW to setup a windmill currently. A 1 MW wind turbine can produce over 3 million kilowatt hours (kWh) of electricity every year (with an approximate PLF of 20-30%). Below are the assumptions that are considered while preparing the economic model.

Table 35: Assumptions for wind energy economic model

S.No.	Parameters	Value	Remarks
1	Area for repurposing	200 Ha	
2	Life of project	20 Years	
3	Size of project	333 MW	
4	Capital cost	734 INR Cr	PwC Analysis
5	Opex	34.65 INR Cr	PwC Analysis
6	Escalation on Opex	2%	PwC Analysis
7	Electricity produced	300 million kwh	PwC Analysis
8	Selling price of electricity	2.99 INR / kwh	PwC Analysis
9	Escalation on selling price	5%	PwC Analysis
10	Discount rate	8.95%	Interest rate by power finance corporation

Source: PwC Analysis

Chart 2: Payback period of wind energy project at mine site



Source: PwC Analysis

11.9. Pros and cons.

Some of the major pros and cons of the wind farm repurposing option have been summarized as follows195:

Table 36: Pros and Cons of Wind power

Pros	Cons
Enhancing the RE portfolio of the state: Developing wind power on the abandoned mines shall add to the overall RE portfolio of the state and contribute to the national RE targets.	High up-front costs: Even though the cost of generating wind energy has decreased drastically in the past decade, the technology still require a high initial investment than conventional fossil-fueled generators.
Increased revenues: A range of stakeholders involved in developing a wind project including energy organizations, local employees, new assembling and manufacturing plants and investors, can add to a states' and municipality's tax stream.	Environmental challenges: The environmental challenges associated with wind farms, both at abandoned mine lands and in general, revolve around the turbines' potential threat to wildlife, primarily bats and local and migratory bird populations.
Revitalization of contaminated property: Utility-scale wind energy projects require a significant amount of land and such projects on formerly contaminated mine lands can generate value. Putting such formerly contaminated properties to use can shift the negative perception associated with abandoned mining lands to valuable assets to the community.	Remediation process: Remediation is the process of returning the mining land to a natural state/state in which it can be used for a different purpose196. In some cases, remediation of the mines shall be required to set up the wind technology. During this process any hazardous material is disposed-off and the land is reshaped to a stable structure while replacing the topsoil and planting vegetation.
Job creation: The construction and operation of a large wind energy project can have a positive impact on the local economy.	Concerns over noise: Wind farms can also generate community concerns about the potential noise levels and aesthetics associated with wind turbines.
Economic development: Fostering local wind energy production allows communities to meet their growing energy demands while facilitating local economic development opportunities.	
Fostering community pride: Wind farms can also serve as local landmarks and sources of community pride.	
Compatibility with remedy: There are several important factors to consider when setting up a wind facility on abandoned mine lands. At underground mine sites, openings, mine workings, and other subsurface passageways may lead to subsidence or other engineering challenges. Records kept by mining companies on subsurface activities at a site can provide valuable information while setting up the wind technology and save on research costs.	

Source: PwC Analysis

11.10. Suitability for India

Setting up wind farms on abandoned mine has been done by Neyveli Lignite Corporation (NLC) India. It has set up a 51 MW wind power generation plant at Kaluneerkulam, Tamil

Nadu. But more such plants can be set up with improved efficiency with proper government policies and technological developments in place.

As per **Indian Wind Energy Association**[197], the incentives that are being provided for wind projects are as follows:

- Concession on import duty on specified wind turbine components.
- 10-year income tax holiday for wind power generation projects.
- Concessional custom duty exemption on certain components of wind electric generators
- 100% exemption from excise duty on certain wind turbine components.
- REC Mechanism.
- Waiver of Inter State Transmission System (ISTS) charges and losses for inter-state sale of solar and wind power for projects to be commissioned up to March 2022.
- Permitting Foreign Direct Investment (FDI) up to 100 percent under the automatic route.
- Notification of standard bidding guidelines to enable distribution licensee to procure wind power at competitive rates in cost effective manner.
- Declaration of trajectory for Renewable Purchase Obligation (RPO) up to the year 2022.
- Implementation of Green Energy Corridor project to facilitate grid integration of large-scale renewable energy capacity addition.
- Technical support includes wind resource assessment and identification of potential sites through the National Institute of Wind Energy, Chennai.
- IREDA finance scheme for wind power projects.
- Special incentives provided for promotion of exports from India for various renewable energy technologies under renewable sector specific SEZ.
- Feed-in-Tariff (FIT) scheme for wind projects upto 25 MW.

Additionally, there is **IREDA New Scheme**[198]: – "Bridge loan against GBI Claims Payable to Renewable Energy Developers under MNRE Scheme for Generation Based Incentive (GBI) for grid interactive Wind and Solar power projects".

<u>Eligibility for discounting of GBI claims</u>

RE developers who have already submitted a valid GBI claim under GBI Scheme at IREDA, which is processed and pending for release of payment on account of nonavailability of funds, will be eligible under this scheme.

<u>Extent of assistance</u>

- Up to 80% of the existing pending eligible GBI claim, as verified by the IREDA GBI group.
- Minimum loan assistance – INR 20 Lakhs.

<u>Determination of loan amount</u>

Based on verification by IREDA- GBI group regarding pending eligible GBI claim of the applicant in line with existing GBI policy.

<u>Interest rate</u>

0.90% p.m. (10.80% pa) to be adjusted from the GBI receipts from MNRE against the claim. Shortfall, if any, will be payable by the borrower on demand. The interest shall be calculated on daily basis and shall be charged during the currency of the Bridge loan/till the same is paid/adjusted against the GBI release by MNRE/paid by the borrower.

Repayment

Loan amount to be recovered out of GBI proceeds received / to be received from MNRE. Shortfall, if any, will be recovered from the borrower, which will be payable on demand.

Security

Charge on GBI receivables from MNRE. The Charge shall be created by the borrower within the stipulated time as indicated by ROC.

As per the Financing Norms And Schemes of IREDA

Minimum Promoter Contribution, Quantum of loan & Maximum Debt Equity Ratio.

a) The quantum of loan from IREDA shall be normally upto 70% of the total project cost.

b) Typically, the minimum promoter contribution shall be 30% of the project cost and the maximum Debt Equity Ratio (DER) shall not be more than 3:1

c) However, in case of Solar & Wind Sector projects, IREDA may consider the minimum promoter contribution as 25% of project cost and may extend loan up to 75% of the project cost subject to meeting the following conditions:

- In case of repeat borrowers of IREDA with an operational RE/EE project, should have a good track record with respect to repayment to the satisfaction of IREDA.
- In the case of new clients, the average Debt Service Coverage Ratio (DSCR) of the project should not be less than 1.3.

d) For all government supported RE Projects, we may follow the guidelines of respective schemes with respect to treatment of such assistance as Promoter contribution/Quasi Equity.

Moratorium & Repayment Period

The repayment periods shall be maximum upto 25 years or 80% of the balance PPA period, whichever is lower, depending on the project cash flows, DSCR of the project etc., and it shall be after the construction and moratorium, with a condition that IREDA shall have the right to call option after 15 years of repayment.

The **Government of India** has taken steps to promote renewable energy[199], including wind energy, which are as follows:

- Permitting Foreign Direct Investment (FDI) up to 100% under the automatic route,
- Waiver of Inter State Transmission System (ISTS) charges for inter-state sale of solar and wind power for projects to be commissioned by 30th June 2025,
- Declaration of trajectory for Renewable Purchase Obligation (RPO) up to the year 2022,
- Setting up of Ultra Mega Renewable Energy Parks to provide land and transmission to RE developers on a plug and play basis,
- Laying of new transmission lines and creating new sub-station capacity for evacuation of renewable power,
- Setting up of Project Development Cell for attracting and facilitating investments,

- Standard Bidding Guidelines for tariff based competitive bidding process for procurement of Power from Grid Connected Solar PV and Wind Projects.
- The government has issued orders that power shall be dispatched against Letter of Credit (LC) or advance payment to ensure timely payment by distribution licensees to RE generators.
- Conducting skill development programs to create a pool of skilled manpower for implementation, operation and maintenance of RE projects.

In addition to the above, the following steps have been taken specifically for promoting wind energy:

- Concessional custom duty exemption on certain components required for manufacturing of wind electric generators.
- Generation Based Incentive (GBI) is being provided to the wind projects commissioned on or before 31 March 2017.
- Technical support includes wind resource assessment and identification of potential sites through the National Institute of Wind Energy, Chennai.

Considering the working principle of wind technology and the conditions determining suitability of wind technology, the suitability of repurposed wind technology in abandoned Indian mines have been analyzed in detail in Section 27.

12. PV on Mining Land (Including Agrivoltaics) - As Repurposing option

12.1. Introduction to repurposing option

As the governments and various agencies are making efforts to reduce the carbon emissions and the `GHG emissions, several efforts have been made to explore more options to generate electricity from the renewable energy resources. As a result, solar energy has seen rapid growth in the generation mix around the world in past many years, this is supported by the decrease in the cost of raw materials and continuous research and development in the technology. India, being the seventh largest country (by area) in the world, has a great solar potential.

The country's solar potential is estimated by the National Institute of Solar Energy to be 748 GW[200], assuming that solar PV modules will cover 3% of the waste land area. The National Solar Mission is one of the main Missions of India's National Action Plan on Climate Change, which has given solar energy a central role. Solar energy is abundant in India and has the potential to generate 5,000 trillion kilowatts of renewable energy. Around 300 sunny days and 4–7 kwh of solar insolation per square meter per day are abundant in the country[201].

As of 2020, on an average a solar panel generates about 320 watts of power, however it will be uncommon to find one that does so. The majority of panels are capable of producing 285 to 360 watts per individual unit. A typical solar panel array is roughly 5kW in size and occupies 400 square feet. This size of array can generate 350–850 kWh of AC electricity on average per month[202]. One MW of electricity requires 5 acres of land, while a utility-scale plant needs at least 200 acres of land to be feasible[203].

The abandoned mine lands prove to be a good place to install the solar panels. There are plenty of reasons because of which we can install solar farms in AML.

- The AML are majorly located in the areas like Andhra Pradesh, Jharkhand, Odisha which receive good amount of sunlight throughout the year. However, states in Western India show more potential of PV[204] and deploying solar plants in western Indian states is more efficient than deploying in eastern states and therefore western states have been the main target for PV expansion.
- Big utility scale solar energy projects require access to large and open sites.
- The AML's already have certain infrastructure like roads, power transmission lines which can help in reducing the cost of project to set up the Solar farm.
- Also, many mine lands are situated in remote areas where there is very limited electricity infrastructure, it makes them suited for the use of solar energy onsite cleanup and reclamation activities.

As of the end of 2021, India is ranked fourth worldwide in the deployment of solar PV. As of the 30 November 2022, the installed capacity of solar energy was approximately 61.97 GW205. India's solar tariffs are currently very competitive and have reached grid parity. To facilitate the power transmission, government is constructing a total of 10,750 km intra-state transmission lines and 27500 MVA sub-stations, under the Intra-State GEC Phase-II (InSTS GEC-II) scheme206. It is noteworthy that 1,12,250 MW is the current Inter State transmission capacity. The total inter-regional transmission capacity is anticipated to be around 1,50,000 MW in 2030 with the new inter-regional transmission lines now being implemented or planned.

12.1.1. Agrivoltaics

The term "Agrivoltaics" (AgriPV) refers to the joint development of a single land area for solar photovoltaic energy and agriculture, enabling the cohabitation of two important sectors. It is an innovative strategy that encourages the creation of shared value with the neighborhood and communities in which the plants are located by allowing agricultural practices and solar energy production to coexist and interact in a mutually beneficial way.

The rapidly expanding and highly promising idea of AgriPV permits the coexistence of two important sectors. AgriPV-projects have already been started in many different forms all over the world, and a wide range of strategies have recently emerged that will play a significant role in the energy and climate transition.

However, for agricultural purposes, fertility of land would be a pivotal factor which might not be feasible completely on abandoned mine lands owing to their infertile land pattern.

12.2. Global best practices with examples

Globally there have been many projects related to repurposing abandoned mine lands into solar power plant. Countries like US, Canada, Germany have built many projects on the mine lands.

12.2.1. The Sunmine, BC, Canada[207]

The Sullivan mine in British Columbia was one of the largest mines producing lead-zinc in the world. The mine started its operation in 1899 after it was discovered in 1896. By the year 1968 the company recognized that the mineral sources are finite, and they need to plan for their eventual depletion. The city established near the mine, started focusing on repurposing the mine and analyze all the options while planning for the mines closure. Mines were closed in 2001 and the reclamation process was completed by 2010. There were many recreational facilities which were established in the mine area, but the city wanted to add more into the portfolio and increase the city’s reputation as an environmentally conscious community and thus they selected setting up of a solar farm.

Figure 62: Solar farm at sunmine

Source : https://www.iisd.org/system/files/2022-01/igf-case-study-post-mining-transition-renewable-energy.pdf

Most of the power in the city of Kimberly British Columbia came from the hydroelectricity, it provided regular supply of electricity but had certain disadvantages due to the construction of the dam. There were many instances of flood in the nearby areas due to the dam and thus the authorities wanted to explore other options for fulfilling British Columbia's energy needs. Proper due diligence feasibility studies and various other research works were done from 2008 to 2014 and finally construction of a solar farm began in 2014. Throughout the construction, in total 29 locals were hired for a full-time job. Also, it was decided that authorities of city of Kimberley would be the primary owner and operator of this solar farm thus making the project distinctively community owned. The site included 96 tracking solar masts which produced total power of 1.05 MW. Sunmine used tracking technology which adjusts the solar panel and track the sun from East to West to collect maximum amount of solar radiations and thus help in generating more electricity and be more efficient than fixed solar projects. The tracking technology at sun mine generates 36% more energy compared to fixed solar projects and the energy generated is sold to BC Hydro through its net metering program.

This project generated more revenues than expected and served 275 homes and displaced approximately 1000 tons of greenhouse gases per year. This project not only reutilized the mainland but also served economic benefits, ecological benefits, employment benefits, and it also experienced an unexpected benefit in the form of tourism and many scientists and school groups visited the site. The owners and the government have anticipated that the solar plant capacity can be increased from 1 MW to up to 200 MW and they are planning for the expansion after seeing the revenue generations and other benefits from the site.

12.2.2. AgriPV on Garzweiler Opencast mine, Germany

Garzweiler mine is a lignite mine which is present in the town of Grevenvbroich in Germany (See picture on page 7). It is owned by RWE Power AG. The mine has been repurposed with Agri-photovoltaic of 3.2 MW output by a big German electricity producer RWE. The demonstration system with an output of 3.2 megawatts was installed on an approximately seven hectare recultivation area on the edge of the Garzweiler opencast mine near Bedburg.

RWE wants to test three different forms of application for agri-photovoltaics, i.e. the generation of solar power and agriculture in one area, in the coming years. This involves both arable and horticultural use of the land.[208]

12.2.3. Chevron Questa Mine, Questa, New Mexico[209]

The Chevron Questa mine formerly known as Molycorp incorporated started the operations in 1920s. The operations for open pit mine ended in 1983 however, underground mining was still in progress. A very large area of the mine land became abandoned, and the authorities decided to install solar farm after doing several research and due diligence. Concentrated photovoltaic (CPV) technology was used to set up this solar farm. This mine land is situated in New Mexico's Sangre de Christo mountains. The mining company completed the site's close out plan in the 1998 and the solar facility planning was started in 2008-2009. The construction of the solar plant finally started in 2010 and it got commissioned in 2011.

In the 21 acres of land a solar farm with 1 MW of capacity was established which produced enough electricity to serve 150 homes. This land was chosen for solar farm because it received over 300 sunny days each year also it had minimal gradient and there was a 12.5 kilo Volt electrical distribution line nearby that connected the solar farm to the nearest electrical distribution center. The electricity generated was sold to a private distribution company, which then sells the electricity to the households in the nearby areas. The distribution company and the mining company had entered into a PPA for 20 years to sell the electricity generated from the solar farm.

All the geotechnical investigations, foundation feasibility assessment and cover analysis were done in order to check the feasibility of the land for the solar farm. During the construction, operations and maintenance work, many local people were hired which earlier worked in the Questa mine. These workers and employees were trained to construct and operate this solar farm. In a period of one year this solar farm generated approximately 2 million kilowatt hours which is roughly equal to the average electricity requirement of 150 homes. Since 2011, this project has been exceeding its expectations and has been performing pretty well.

Figure 63: Solar panels at chevron questa mine

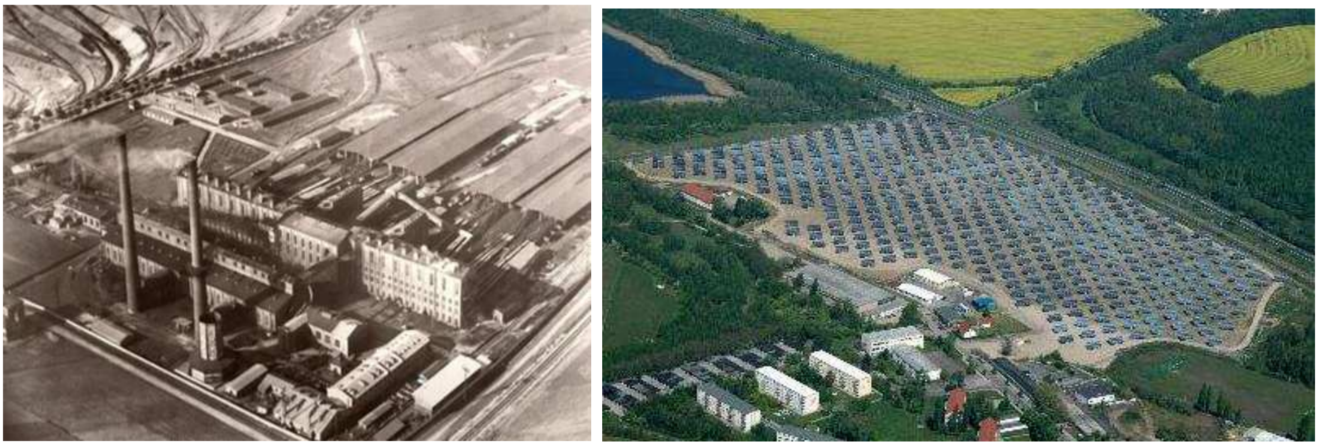
Source: https://semspub.epa.gov/work/HQ/190025.pdf

This 1 MW solar farm saves around 1044 tons of carbon dioxide, 1.6 tons of nitrogen oxide and 0.7 tons of sulfur dioxide. This project not only provides ecological benefits by reducing the emissions but also provides several economic benefits by generating extra revenue giving employment to many people and also reestablishes the value for the land.

12.2.4. Leipziger Land Solar Power Plant[210]

There was a lignite-mine ash deposit in Espenhain, Germany. These 49 acres of land became abandoned, and a solar farm was constructed which started its operation in 2004.

Figure 64: Solar plant at lignite mine



Source: https://semspub.epa.gov/work/HQ/176032.pdf

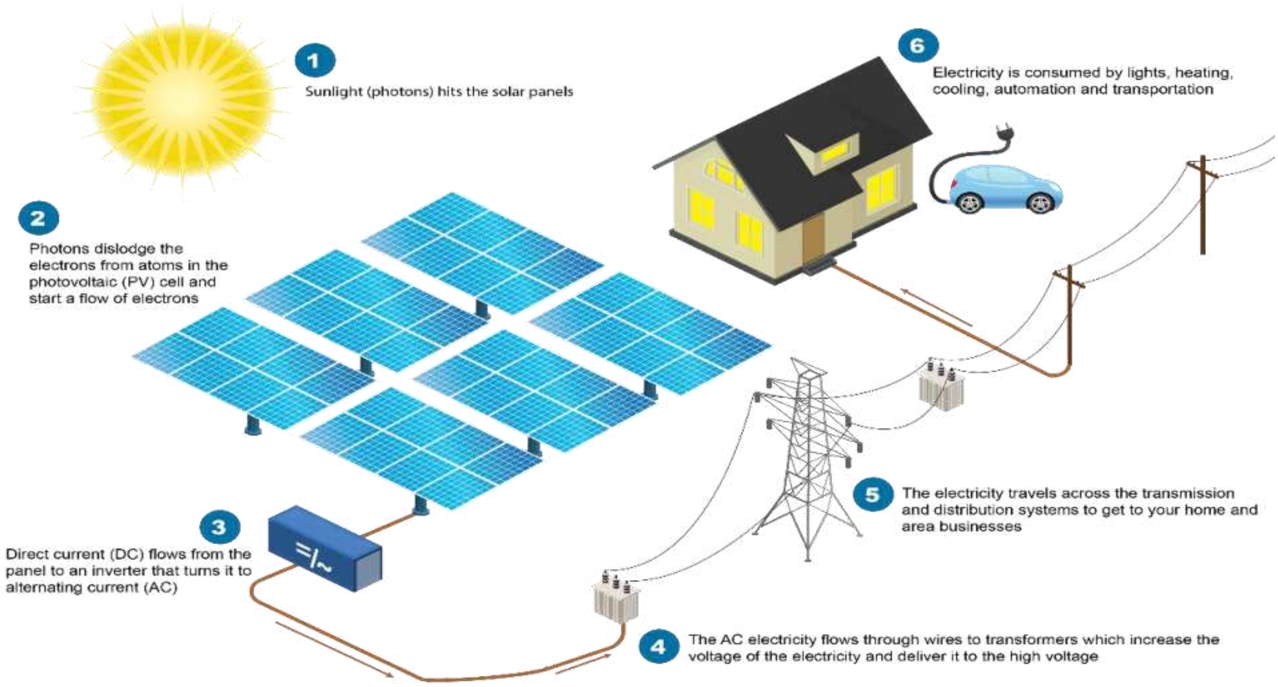
The 5 MW photovoltaic power plant is made-up of 33,500 solar modules and the electricity generated from this farm is fed directly into the German electricity grid. These solar modules are installed at the site with the help of the wood framing method that relied on the local material. After the mine sees its operations, the on-site contamination was addressed, and a lot of lignite was buried under a foot of soil before the construction of the solar farm was started. The solar plant gave employment to local people and also served as a source of extra revenue for the DISCOM and the mine owner. As can be seen from the pictures above, establishing the solar farm changed the scenic beauty of the area and restored the value.

An abandoned query in China was converted into a 50 MW agriculture photovoltaic complementary photovoltaic plant that is into an Agrivoltaic farm. There are many cases of Agrivoltaic however, setting up Agrivoltaic farm on abandoned mine lands is new and can be explored more as an option to utilize the land with the greater efficiency.

12.3. Working principle of technology

The solar farms produce electricity with the help of the photons that comes from the sun. The photons from the sun hit the solar panels which are arranged in an array, these photons dislodge from atoms in the photovoltaic cell flow of electrons. This flow of electrons produces a direct current which is converted into alternating current with the help of an inverter. The AC electricity is then stepped up to higher voltage with the help of the transformer and is send through the power transmission lines homes and industries.

Figure 65:Working principle of solar energy generation



Source: https://www.cidersolarfarm.com/assets/img/how_solar.png

On an average the inclination angle of the solar panels is around 45° towards the south so that they capture most of the sun rays falling on them. Sometimes trackers are also used in the solar panels which help in capturing more amount of sunlight as the solar panels move from east to west along with the sun. Also, it is favorable to have a sloppy land with an inclination towards South or East.

12.4. Conditions determining suitability of technology

The conditions which are suitable to install the solar farms in area that is the abandoned mine lands in this case are:

- Solar farms require a vast area of land. It is a thumb rule that 1 kilowatt of solar panels require an area of 100 square feet also it can be said that for 5 acres of land 1 MW of energy can be produced and for a feasible utility scale project a minimum of 200 acre of land is required considering that only 60% of the total area is covered with solar panels[211]
- The land should be wide and open with no wetlands and minimal incline. The inclination of the land also matters while installing the solar panels, on an average an inclination of five degree in the land is acceptable. However, it has been seen that some amount of

inclination and the lands facing towards East or South are beneficial for such power plants as they help in capturing majority of the sunlight. Trackers can also be used in order to capture the maximum amount of sunlight and hence increase the efficiency of the plant.

- The solar farm should be in proximity to sub-station or three phase power, it is better to have a grid nearby so that the cost of interconnection can be kept as low as possible.
- The region should receive plenty of sunlight for the maximum number of days throughout the year to make the project feasible. However, it should be noted that extreme temperatures can cause damage to the panels.

12.5. Potential for symbiosis with other repurposing options

Table 37: Potential symbiosis with PV on mining land

Repurposing options	Degree to which options can be combined
Pumped Storage Hydropower	Solar PV can be used to pump water during off-pick time and can help in releasing energy during peak time through Pico hydro turbine to ensure stability in energy flow. Solar PV can be a potential substitute to the conventional diesel-based hydro pumping system[212]. The main storage technology used for both stand-alone and grid-connected PV systems is based on batteries, but other solutions like water/seawater pumped storage can be considered. From the life cycle assessment used to compare Energy Storage System (ESS) of different nature, it emerged that PHS have the highest Energy Storage On Energy Invested (ESOI) index of 210. ESOI is the total amount of energy stored over the lifetime of a storage technology unit, divided by the amount of energy used in producing that unit, i.e. kWh/kWh. Among the batteries Li-ion has the highest ESOI, that is 10, evidently much lower than PHS[213].
Thermal Energy storage	Solar thermal power plant, a combination of solar energy and thermal energy, where the sun's radiation is used to fuel the power plant. Solar energy is converted into thermal or heat energy which is then converted into mechanical energy through turbine and energy is generated using generators[214].
Wind Energy on Mining Land	A pilot test has been carried out in Breña wind farm, on one of the wind turbines that is owned by ACCIONA. On the wind turbine they have set up 120 solar panels that are installed in fifty meters of height on the tower, with a power of 9.36 kilowatts peak. To optimize the capture of solar energy, the panels have been integrated with a southeast-southwest orientation. Organic solar panels are being used that are barely one millimeter thick, and use carbon as raw material, offering lightness and great structural flexibility, and are recyclable. These panels also have low maintenance costs[215]. In the US, during winter the wind is strong and comparatively less sunlight is available whereas in summer the wind speeds are low, and the sun shines brighter for a long duration. Since the peak operating time for wind and solar systems are different and mostly opposite, hybrid systems ensure energy can be provides whenever there is a need[216].
Compressed Air Energy Storage	The storage technology used for both stand-alone and grid-connected PV systems is based on batteries, but other solutions such as compressed air energy storage can be considered. From the life cycle assessment used to compare Energy Storage System (ESS) of different nature, it emerged that the traditional CAES have the highest Energy Storage on Energy Invested (ESOI) index of 240. ESOI is the total amount of energy stored over the lifetime of a storage technology unit, divided by the amount of energy used in producing that unit, i.e. kWh/kWh. Among the batteries Li-ion has the highest ESOI, that is 10, evidently much lower than CAES[217].

Source: PwC Analysis

Solar power generation options can be optimally combined with wind generation options under wind-solar hybrid project mechanism. Several such projects have come up globally where wind and solar assets have been co-located for optimized generation. Please refer section 26 for symbiosis between PV and other repurposing options.

12.6. Potential environmental impact locally and GHG emission reduction potential

Some of the environmental impact by the repurposed solar photovoltaic technology are:

Solar projects on an AML can increase the priority to clean up those sites, this may remove or repair the buildings, clean the contamination from water and thus local ecosystem can be restored as well.

Photovoltaic plants or the solar plants do not emit greenhouse gases unlike the coal, natural gas and oil extraction mines.

The cleanup of tailing pipes to make a site ready cleans up the contaminated water and can help prevent contamination of drinking water sources.

Cleanup of sites along the rivers also helps in protecting the aquatic ecosystem from contaminant impacts.

12.7. Employment effects

Repurposing an abandoned mine land can help in generating revenue for the state or country as well as generating employment for the people. Construction and pre-construction activities of setting up a solar power plant (PV) can generate 75 to 500 employment opportunities for the skilled and unskilled labor whereas the operation and management of the solar power plant can generate 5 to 15 employment opportunities depending upon the size of project in both scenarios[218]. The number of skilled and unskilled employees that are hired increases as the size of the project increases.

12.8. Economic feasibility analysis

We have prepared an economic model based on the installation of solar PV on abandoned mining land for which assumptions taken are tabulated below.

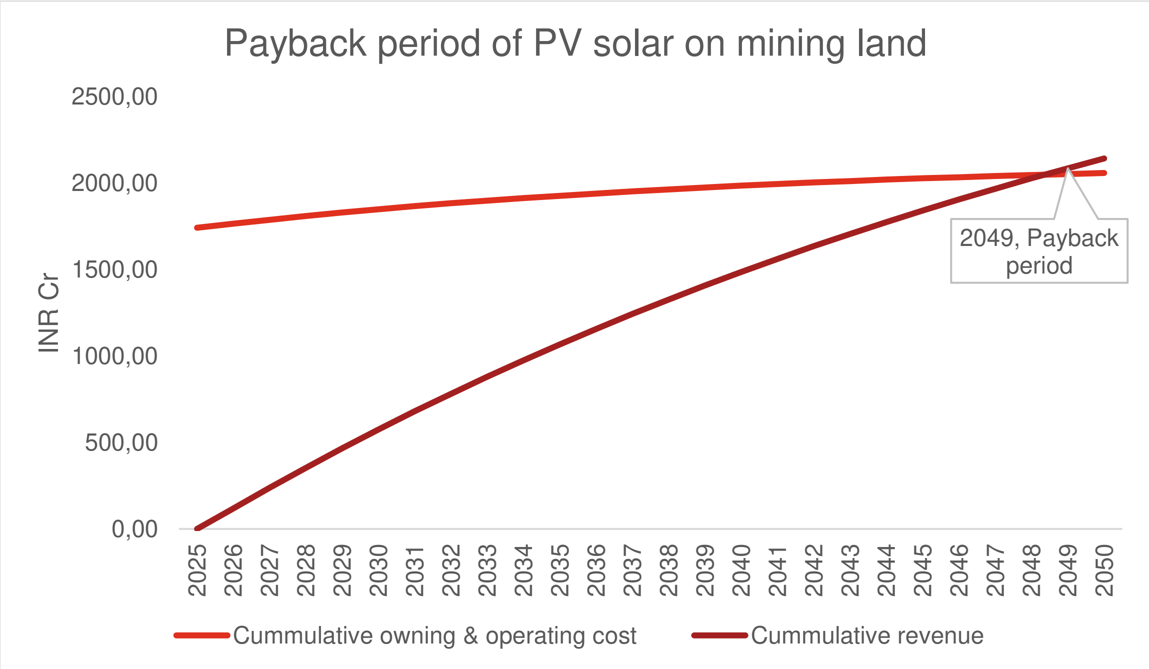
Table 38: Assumptions for PV on mining land economic model

S.No.	Parameters	Value	Remarks
1	Area for repurposing	200 Ha	
2	Life of project	25 Years	
3	Size of project	332 MW	
4	Capital cost	1743 INR Cr	PwC Analysis
5	Opex	27.89 INR Cr	PwC Analysis

S.No.	Parameters	Value	Remarks
6	Escalation on Opex	2%	PwC Analysis
7	Electricity produced	464.8 million kwh	PwC Analysis
8	Selling price of electricity	2.99 INR / kwh	PwC Analysis
9	Escalation on selling price	5%	PwC Analysis
10	Discount rate	8.50%	Interest rate by power finance corporation

Source: PwC Analysis

Chart 3: Payback period of solar energy project on mine site



Source: PwC Analysis

12.9. Pros and cons

Table 39: Pros and Cons of PV on mine land

Pros	Cons
Enhancing the RE portfolio of the state: Building solar farms on the former mine sites will boost the state's overall renewable energy portfolio and help it meet its national ambitions.	**High up-front costs:** Although the cost of producing solar energy has significantly fallen over the past ten years, the technology still requires a larger upfront investment than standard fossil-fueled generators.
Increased revenues: A state's and municipality's tax revenue may increase as a result of a variety of stakeholders involved in the development of a solar project, such as investors, energy organizations, local employees, and new assembling and manufacturing facilities	**Solar intermittence:** Utility-scale energy installations must be able to deliver a dependable, steady supply of electricity. Solar facilities must be able to either store solar electricity or augment their supply with another source of energy to account for the intermittent nature of solar energy.

Pros	Cons
Revitalization of contaminated property: Utility-scale solar PV projects need a lot of land, and they can be profitable on old mine areas that have been contaminated. Utilizing such formerly contaminated areas might change the negative reputation of abandoned mining grounds and turn them into one of the community's most prized assets.	**Transmission access:** It is essential to have access to local transmission lines when establishing large-scale solar power installations. Establishing a solar farm can be expensive if they are far away.
Job creation: The construction and operation of a large solar PV project have a positive impact on a local economy.	**Increased water demand:** A solar thermal facility's capacity to access vast quantities of water is essential to its success.
Economic development: Communities can fulfill their increasing energy needs while fostering local economic development prospects by promoting local solar PV manufacturing.	
Fostering community pride: Solar farms can act as landmarks and a source of pride for the neighborhood if implemented with local ownership options and including local revenue streams.	
Compatibility with remedy: When building a solar farm on former mine sites, there are a number of crucial considerations. Openings, mine workings, and other subterranean passageways at underground mine sites could cause subsidence or other engineering difficulties. When installing solar technology, records kept by mining companies on underground activities at a site can be very helpful and save money on research.	

Source: PwC Analysis

12.10. Suitability for India

Singareni Collieries Company Limited (SCCL) has already envisaged an 800 MW solar power plant, including 500 MW floating solar in Telangana. Of the 300 MW, the company has completed 30 MW at Manuguru and 10 MW at Jaipur. Quite a few factors need to be considered before setting up a PV, firstly and most importantly the solar radiance of the particular place and then other conditions as mentioned above. Other factors that can play a role in setting up more such plants include government policies, and technological advancements that make them more efficient.

Some of the scheme and policies that have been initiated by the government and are in place to support the PV projects are as follows[219]:

Table 40: Schemes available to set up PV

Scheme	Short details
Central Public Sector Undertaking (CPSU) Scheme Phase-II (Government Producer Scheme) for grid-connected Solar Photovoltaic (PV) Power Projects by the Government Producers.	Viability Gap Funding (VGF) support up to INR 55 lakhs per MW to the CPSUs/Govt. Organizations entities selected through competitive bidding process.

Scheme	Short details
PLI Scheme 'National Program on High Efficiency Solar PV Modules'	The beneficiaries are eligible for Production Linked Incentive (PLI) on production and sale of solar PV modules. The quantum of PLI eligible for disbursal depends upon: • quantum of sales of solar PV modules. • performance parameters (efficiency and temperature coefficient of maximum power) of solar PV modules sold; and • percentage of local value addition in modules sold.
Solar Park Scheme	Up to INR 25 lakhs per Solar Park, for preparation of Detailed Project Report (DPR). INR 20 Lakh per MW or 30% of the project cost, whichever is lower, for development of infrastructure.
PM-KUSUM scheme	**Component A:** Setting up of 10,000 MW of Decentralized Ground/Stilt Mounted Solar Power Plants Benefit available: Procurement Based Incentive (PBI) to the DISCOMs at 40 paise/kWh or INR 6.60 lakhs/MW/year, whichever is lower, for buying solar power under this scheme. The PBI is given to the DISCOMs for a period of five years from the Commercial Operation Date of the plant. Therefore, the total PBI that payable to DISCOMs is upto INR 33 Lakh per MW. **Component B:** Installation of 20 Lakh Stand-alone Solar Pumps Benefit available: CFA of 30% of the benchmark cost or the tender cost, whichever is lower, of the stand-alone solar agriculture pump is provided. However, in North Eastern States, Sikkim, Jammu & Kashmir, Ladakh, Himachal Pradesh and Uttarakhand, Lakshadweep and A&N Islands, CFA of 50% of the benchmark cost or the tender cost, whichever is lower, of the stand-alone solar pump is provided. **Component C:** Solarization of 15 Lakh Grid Connected Agriculture Pumps including through feeder level solarization. • Individual Pump Solarization: CFA of 30% of the benchmark cost or the tender cost, whichever is lower, of the solar PV component will be provided. However, in North Eastern States, Sikkim, Jammu & Kashmir, Ladakh, Himachal Pradesh and Uttarakhand, Lakshadweep and A&N Islands, CFA of 50% of the benchmark cost or the tender cost, whichever is lower, of the solar PV component is provided. • Feeder Level Solarization: Agriculture feeders can be solarized by the State Government in CAPEX or RESCO mode with CFA of INR 1.05 Crore per MW available from MNRE. However in North Eastern States, Sikkim, Jammu & Kashmir, Ladakh, Himachal Pradesh, Uttarakhand, Lakshadweep and Andaman & Nicobar Island, CFA of INR 1.75 crore per MW is available.

Scheme	Short details
Green Energy Corridor Scheme (for development of intra-state transmission system for RE projects)	GEC Phase-I: CFA of 40 % of DPR cost or awarded cost whichever is lower. GEC Phase-II: CFA of 33 % of DPR cost or awarded cost whichever is lower.
Development of Solar Parks and Ultra Mega Solar Power Projects	Total central financial support of INR 34,422 Cr is envisaged under the PM-KUSUM Scheme, which has been extended till 31.03.2026. The Scheme is a demand driven scheme and capacities are allocated, under the Scheme based on the demand received from the states/UTs. Under the Scheme for Development of Solar Parks and Ultra Mega Solar Power Projects, total of 57 solar parks of aggregate capacity 39,285 MW have been sanctioned till 30.11.2022.

Source: https://pib.gov.in/PressReleasePage.aspx?PRID=1911485

Development of Solar Parks and Ultra Mega Solar Power Projects[220]

Table 41: Various modes of development of solar park

Mode	Brief Description	CFA Pattern
Mode-1	• The State designated nodal agency or a State Government Public Sector Undertaking (PSU) or a Special Purpose Vehicle (SPV) of the State Government. • Central Public Sector Undertakings (CPSUs) like SECI, NTPC etc.	INR 12 lakh/MW or 30 % of the project cost to SPPD for development of internal infrastructure, and INR 8 lakh/MW or 30 % of the project cost to the CTU/STU for creation of external transmission infrastructure.
Mode-2	A Joint Venture Company of State designated nodal agency and Solar Energy Corporation of India Ltd (SECI).	INR 12 lakh/MW or 30 % of the project cost to SPPD for development of internal infrastructure,
Mode-3	The State designates SECI as the nodal agency	INR 12 lakh/MW or 30 % of the project cost to SPPD for development of internal infrastructure,
Mode-4	Private entrepreneurs with / without equity participation from the State Government	INR 12 lakh/MW or 30 % of the project cost to SPPD for development of internal infrastructure,
Mode-5	Private entrepreneurs without any Central Financial Assistance from MNRE	No CFA
Mode-6	SECI will act as the Solar Power Park Developer (SPPD) for Renewable Energy Parks	INR 20 lakh/MW or 30 % of the project cost for external transmission infrastructure only.
Mode-7	CPSU/ state PSU/ Government organization/ their subsidiaries or	INR 20 lakh/MW or 30% of the project cost for internal infrastructure only.

Mode	Brief Description	CFA Pattern
	the JV of above entities can act as SPPD.	

Source: https://mnre.gov.in/development-of-solar-parks-and-ultra-mega-solar-power-projects/

Considering the working principle of solar PV technology and the conditions determining suitability of PV technology, the suitability of repurposed solar PV technology in abandoned Indian mines have been analyzed in detail in Section 27.

13. Floating Solar – (Also in combination in Fish Cage Culture) - As Repurposing option

13.1. Introduction to repurposing option

For the past many decades, efforts have been made to find the alternatives to the fossil fuel which emit less greenhouse gases and are sustainable towards the environment. Floating solar is one such alternative which saves emission of greenhouse gases and it's sustainable. India has a great solar potential which can be utilized to diversify the energy generation mix portfolio for the country. According to a study done by The Energy and Resources Institute (TERI) in 2020 the reservoirs covering an area of 18,000 square kilometer in India can generate up to 280 GW through floating solar panels. Currently, the largest rooting solar power plant in India is the Ramagundam in Peddapalli district of Telangana with a capacity of 100 MW[221].

A solar panel typically produces around 320 watts of power, although this is the ideal production. Most panels have an individual output capacity of 285 to 360 watts. A typical solar panel array is 400 square feet in area and has a 5kW capacity. An array of this size may produce 350–850 kWh of AC electricity on average per month[222]. 1 MW of electricity only requires 5 acres of land, whereas a utility-scale plant needs at least 200 acres of land to be feasible[223].

Several flooded open caste abandoned mines are suitable for establishing a floating solar power plant which will not only change the landscape of the area but will also be helpful in generating renewal energy and extra revenue. These flooded abandoned mines are suitable for floating solar power plants because of the following reasons:

- Floating solar power plants require a water body which is wide and open and receives continuous sunlight.
- Flooded abandoned mine lands contain water which is rich in minerals and thus is not suitable for other purposes and so floating solar power plant is the best option.
- Abandoned mine lands already have certain infrastructure like access to roads and transmission lines which will help in reducing the cost of the project.
- The mine lands are situated in remote areas where there is very limited electricity infrastructure and therefore setting up a floating solar plant will help in establishing a better infrastructure in these areas.
- There are flooded mines in the states like Andhra Pradesh, Chhattisgarh, Madhya Pradesh etc. which receive plenty of sunlight and have good solar potential.

The technology for floating solar power plants has been developed on a global scale and is now utilized to establish the floating solar power plants. The technology readiness level of floating solar is in deployment stage as there are several floating solar farms which have been set up on lakes or reservoirs.

13.1.1. Floatovoltaics with Fish Farms

With increasing interest of the renewable energy developers towards the floating solar power plants (floatovoltaics), options are being searched for making it more sustainable and more useful. Mixing fish farming with floatovoltaics is one such effort which proved to be a good option and has made floatovoltaics more sustainable and useful. Many countries have started building solar farms near to fish farms which help them in several ways. These floating solar farms do not impact much on the fish life, in fact in some conditions they aid to better living conditions for the aquatic life by keeping the water temperature low and blocking the strong solar radiation. These farms have better power conversion efficiency as they also convert the reflected sunlight from the lake and keep the panels relatively cool also, they significantly reduce evaporation of water bodies thus helping to retain the water for longer period of time.

In most of the cases, the solar panels are mounted on top of the mast which are fixed to the bottom of the water body, or they can be floated on water surface with the help of the floats. These floating solar farms can be a solution to sustainable food-energy-water nexus. However, implementing this solution in a flooded abandoned mine can be challenging because the water in the coal mines is rich in chemical components which might not be suitable for fish farming.

13.2. Global best practices with examples

China is one of the countries that made the floating solar power plant on an abandoned mine land. Currently there are two cases in China, on the other hand several countries have started looking towards floating solar power plants as an option to repurpose the flooded abandoned mines. Some of the global cases regarding floating solar on mine land and normal floating solar with pisciculture are:

13.2.1. Floating Solar Plant atop coal mine, Anhui, China[224][225]

Fighting with the air pollution in their country China has started investing heavily in renewable energy. The air pollution has taken many lives in China and the government has started taking serious actions against it. In one such effort the government has built a floating solar plant on a closed coal mine which got flooded overtime. Chinese determined to open more such floating power plants and is doing it on a large scale. This floating solar power plant has been upgraded over time and was the largest floating solar plant when it was inaugurated.

Figure 66: Floating solar power plant at an abandoned coal mine in China

Source: https://time.com/china-massive-floating-solar-field/

This floating solar power plant when inaugurated ha a capacity of 40 MW which is enough to power 15,000 homes. This floating solar power plant consists of 1,66,000 solar modules floating on top of the floats made-up of polyethylene or equivalent floatable materials. This solar power plant covers an area of more than 63 hectares. The whole solar power plant is made by combining several islands made of floats. The floats are anchored to the bottom clay silk in order to prevent any movement of the floats and keep the solar panel stable. The infrastructure nearby helped to reduce the transmission cost of the project, as it was a coal mine and the road access and transmission lines were already in place.

These floating solar panels are more efficient than the ground solar panels because the water evaporating from the lake keeps the floating solar cool as compared to the land solar panels. Also, the water evaporation is reduced which helps in retaining the water of the lake for a longer period of time. Establishing a floating solar plant is costlier than the land solar plant because of the added cost of floats, but the floating solar are more efficient and they produce more electricity as they also capture the sunrays reflecting from the water surface and use them to generate electricity.

13.2.2. Second Floating solar in China[226]

A year after the floating solar plant was opened in Anhui province of China, another floating solar power plant was opened in 2018 on the flooded mines in Huainan city of China. This floating solar plant has a capacity of 150 MW, and thus became the largest floating solar plant in the world. This plant was set up as an effort from the Chinese government to decrease the air pollution from their country and increase the renewable portfolio.

The floating solar power plant came up in 2018 with a total capacity of 150 MW enough to power approximately 94,000 homes when run at full capacity. This floating solar plant has changed the landscape of the area and has provided employment opportunities for the local people. The coal mine had existing infrastructure which helped the developers to reduce the cost of the project.

There are several floating power plants being built in India and other parts of the world. The developers are trying to build a hybrid floating solar plant along with fish farming in the region. This photovoltaics combined with fish farming has attracted attention of many nations and countries like Bangladesh have also invested in such projects. Here are links to such articles:

https://english.news.cn/20230615/4a590249fa3a4ae9a5cce6eac79e8209/c.html

https://interestingengineering.com/innovation/fishery-china-giant-solar-plant

13.3. Working principle of technology

When the photons from the sunrays hit the solar panel, they release the electrons from the atoms. These electrons flow from the panels thus generating the direct current. This direct current is converted into alternating current with the help of the inverters. These inverters are one of the important devices in a solar plant. The alternating current is then stepped to transmittable voltage with the help of the transformers which is then sent to the houses for the utilization.

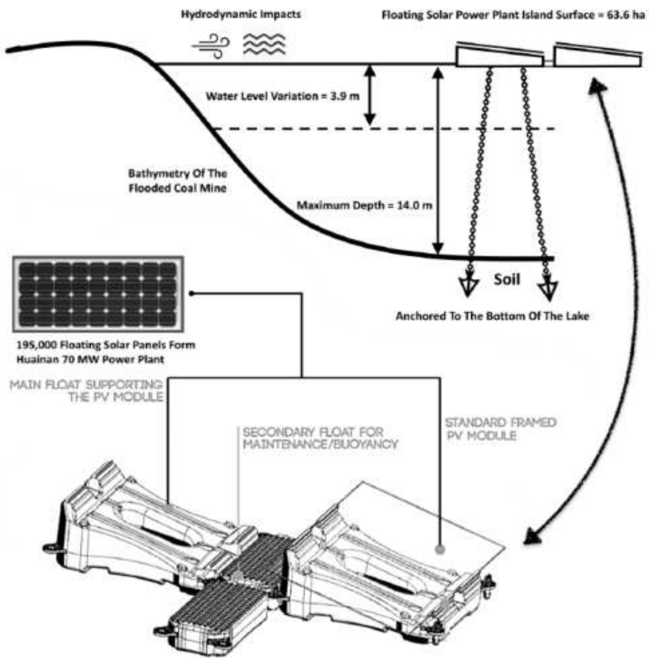


Figure 67: Working principle of floating solar PV

Source: https://wlv.openrepository.com/bitstream/handle/2436/621797/From%20Collapsed%20Coal%20Mines.pdf?sequence=2&isAllo

The solar panels are mounted on a floatable mount or are mounted on a mast which are fixed underground (in case of shallow water). The floats are made of high-density polyethylene which helps the panels to float above the water surface. The solar module, buoyancy body, and anti-rust material, which includes the vertical and horizontal frames, inspection footrest, and module mount assembly, make up a floating solar power plant. The floatables are anchored to the bottom of the water body. The inclination of the panels is approximately 45 degrees towards the south to capture maximum of the sunrays during the day.

13.4. Conditions determining suitability of technology

The conditions which are suitable for establishing a floating solar plant are:

- The water should be still and should receive sunlight for a maximum amount of time during the day.

- The area should be wide and open, without restrictions in nearby areas.
- The solar farm should be in proximity of the grid or a substation so that the cost of interconnection can be kept as low as possible.
- Floating solar farms require a large area of water body.

The floating solar panels have an advantage due to the water evaporation that it helps to keep the panels cool and thus protecting the solar panels from extreme temperatures. Also, floating solar farms do not require flat surface/ground and thus save ground leveling cost.

13.5. Potential for symbiosis with other repurposing options

Table 42: Potential symbiosis with floating solar

Repurposing options	Degree to which options can be combined
Ecotourism	Floating solar farms can be set up with or in ecotourism and that brings the following benefits with the set up. • Utilizing water surfaces efficiently for clean energy production. • Increase in electricity generation due to cooling effect of water. • Positive impact on the environment with reduced evaporation and CO_2 emissions. • Attracting visitors with visually appealing and eco-friendly features and creating eco-tourism opportunities. • Enhancing aquatic biodiversity and acting as sanctuaries for birds[227].
Water Storage & Flood Protection	Certain pit lakes are not suitable for tourism, recreational activities, nature conservation or landscape protection. Setting up a floating solar plant can a suitable option rather than leaving the lake idle and unutilized.
Pisciculture	In Norway, Inseanergy has developed a floating solar technology for aquaculture projects where in it has set up 290 kW floater for salmon-farming and a 160-kW installation for a cod fish farm. The SUB Solar system has been installed on recycled fish-cage float rings and will be used with the onshore power supplies to power fish farms[228].
Hydrogen Storage	Repsol Technology Lab has a pioneering project to produce green hydrogen from floating PV in Cantabria. The project will be set up on a water surface owned by the Santander Port Authority (APS) and the developers will be focusing on designing and constructing a prototype plant for offshore hydrogen and green ammonia production, powered by floating solar arrays[229].
Compressed Air Energy Storage	Excess energy generated by the floating solar plant can be used to compresses the air in the abandoned underground mines. When electricity demand increases, the compressed air is released to run the turbines, generating electricity to meet the demand. The combination of these two options is an eco-friendly solution to manage the energy demands.

Source: PwC Analysis

Solar power generation options can be optimally combined with wind generation options under wind-solar hybrid project mechanism. Several such projects have come up globally where wind and solar assets have been co-located for optimized generation. Detailed analysis of symbiosis of solar power with other repurposing options has been summarized in Section 26.

13.6. Potential environmental impact locally and GHG emission reduction potential

Floating solar plants have many positive impacts on the environment. These plants not only help in reducing the green-house gases but also reduce the water evaporation rate which helps in water retention. Some of the advantages are:

- They improve the landscape of the area and bring pride to the community.
- They help in retaining the water by reducing the evaporation rate, thus increasing water security in water scarce areas and improving the ground water cycle.
- They do not require land preparation and utilize the degraded area, hence converting the habitat.

Utility-scale solar electricity generates between 394 and 447 MWh per acre each year, according to the Lawrence Berkeley National Laboratory. As a result, an acre of solar panels emitting zero carbon dioxide per year saves between 121 and 138 metric tons of carbon dioxide[230].

13.7. Employment effects

A small scale floating solar power plant (<1 MW) can employ directly up to 58 workers whereas mid-scale projects (<10 MW) can employ up to 45 workers[231]. Apart from this it generates indirect jobs in construction, manufacturing of specialized components like floats anchors and other devices. Along with the abilities necessary for ground mounted solar operations, the floating solar plants offer chances for those trained in hydraulic engineering, marine architecture, and plastic blow-molding processes.

13.8. Economic feasibility analysis

We have prepared an economic model based on the installation of floating solar on abandoned mining land for which assumptions taken are tabulated below.

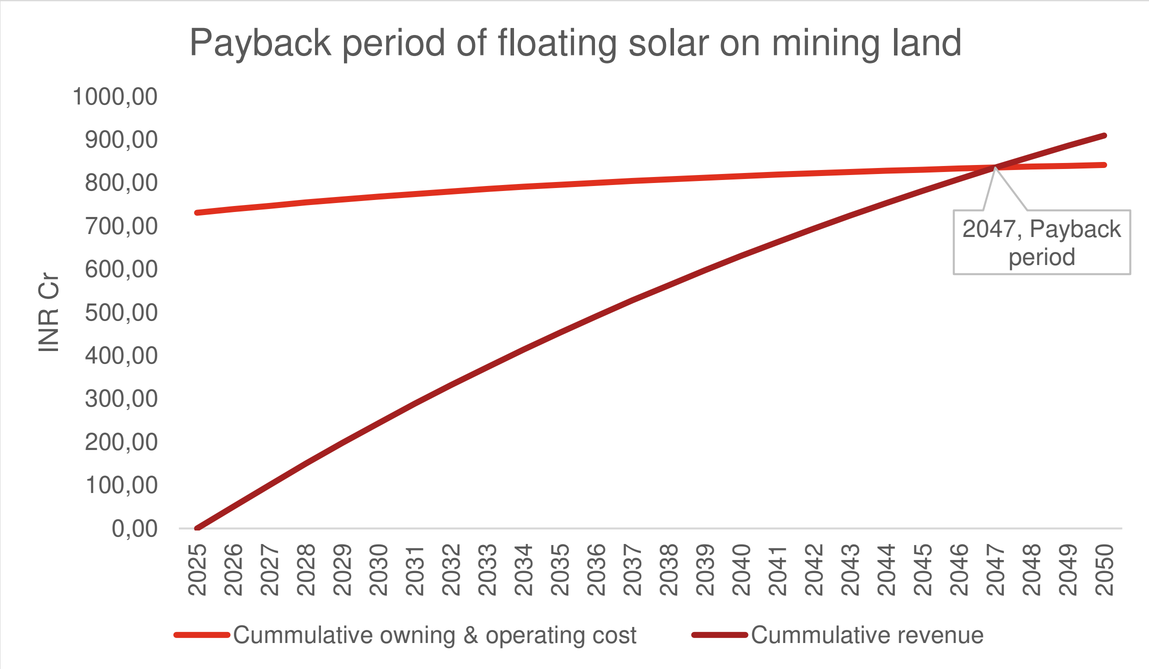
Table 43: Assumptions for economic model of floating solar on mining land

S.No.	Parameters	Value	Remarks
1	Area for repurposing	200 Ha	
2	Life of project	25 Years	
3	Size of project	116 MW	
4	Capital cost	730.80 INR Cr	PwC Analysis

S.No.	Parameters	Value	Remarks
5	Opex	9.74 INR Cr	PwC Analysis
6	Escalation on Opex	2%	PwC Analysis
7	Electricity produced	197.2 million kwh	PwC Analysis
8	Selling price of electricity	2.99 INR / kwh	PwC Analysis
9	Escalation on selling price	5%	PwC Analysis
10	Discount rate	8.50%	Interest rate by power finance corporation

Source: PwC Analysis

Chart 4: Payback period of solar energy project on mine site



Source: PwC Analysis

13.9. Pros and cons

Table 44: Pros and Cons of floating solar

Pros	Cons
Enhancing the RE portfolio of the state: Building floating solar plant on the flooded mine sites will boost the state's overall renewable energy portfolio and help it meet its national ambitions.	**High up-front costs:** Although the cost of producing solar energy has significantly fallen over the past ten years, but the floats increase the overall cost of the project
Water Conservation: Solar panels reduce the evaporation rate thus protecting the water body, also the water vapors keep the panels clean. In order to	**Solar intermittence:** Utility scale energy installations must provide a regular supply of electricity and these plants need to either store energy or augment their supply with another source of energy

Pros	Cons
clean the solar panels, water can be reused from the mine itself.	
Revitalization of contaminated property: Large scale floating solar plants take up large area and change the landscape of the area. Thus, bringing the community pride back to the land and also are profitable on flooded mines changing the negative reputation	**Transmission access:** It is essential to have access to local transmission lines when establishing large-scale solar power installations.
Economic development: Communities can fulfill their increasing energy needs while fostering local economic development prospects by promoting local solar PV manufacturing.	**Safety:** With water involved, it becomes important to ensure that all connections are waterproof and do not pose any threat at any point of time
Increased revenues: A state's and municipality's tax revenue may increase as of variety of stakeholders are involved	**Stability:** Keeping the floats stable is a challenge which requires installation of complex mooring and anchoring
Compatibility with remedy: When building a floating solar farm on former mine sites, there are a number of crucial considerations. Openings, mine workings, and other subterranean passageways at underground mine sites could cause subsidence or other engineering difficulties. When installing solar technology, records kept by mining companies on underground activities at a site can be very helpful and save money on research.	
Job creation – the construction and operation of floating solar projects have a positive impact on localjob creation	

Source: PwC Analysis

13.10. Suitability for India

To set up the plants other factors that are also required are government policies, incentives and technological development to make them operate efficiently.

Singareni Collieries Company Ltd (SCCL) has commissioned a floating solar power plant of 5 MW capacity on the reservoir waters of 2x600 MW thermal power plant situated at Pegadapalli, Jaipur[232].

Considering the working principle of floating solar technology and the conditions determining suitability of solar technology, the suitability of repurposed floating solar technology in abandoned Indian mines have been analyzed in detail in Section 27.3.

14. Geothermal Energy - As Repurposing option

14.1. Introduction to repurposing option

Geothermal energy is a clean and inexhaustible source of energy, like solar and wind energy, which exists in the depths of earth. After the first plant, established in 1904 in Italy, geothermal energy has seen some developments in many countries and several plants are operational world-wide. The technology is still in development phase in India, and the focus is on making geothermal cost competitive. One project in Puga, Leh and Ladakh is under development in India and another one is proposed in Arunachal Pradesh. It is estimated that the geothermal potential in India is about 10GW. According to the surveys conducted by the Geological Survey of India (GSI) there are about 300 geothermal hotspots in India, which ranges in medium potential (100 °C – 200 °C) and low potential (<100 °C)[233].

Geothermal plants can be established on the flooded abandoned underground mine lands where locality is established nearby the mine. The reason why geothermal will be suitable as a repurposing option are:

- To harness geothermal energy, holes are drilled in the ground, underground mines have deep drills up to few hundred meter which serves the requirement.
- Geothermal heat pumps and district heaters require water which remains at a constant temperature, mine water serves this purpose as water in mine exchanges heat with the ground keeping itself at a constant temperature.
- Abandoned mine lands provide much existing infrastructure and connectivity to grid and towns via roads, thus helping in easy transmission of the electricity generated.
- A few abandoned mines have established localities/towns near them, which are advantageous for the geothermal district heaters and the heat pumps, since heat pumps and district heaters are utilized for supplying heated air or water to the households or buildings.

When it comes to utilizing the abandoned mines as a source for geothermal energy, mostly it is used as a heat pump or heat exchanger to heat/cool the buildings or locality or to provide hot water to them. In order to generate electricity from geothermal power, temperatures of about 80-150 degree Celsius are required which are attained at the depth of few kilometers.

14.2. Global best practices with examples

Globally geothermal energy from the mines is majorly used for heat pumps and the district heaters, however there are couple of electricity generating plants were established on the mines in Papua New Guinea and Canada. Geothermal energy is still emerging as a feasible option and many research and developments are going on to make the technology available at level of other renewable options.

14.2.1. Geothermal power plant on gold mine in Papua New Guinea[234]

A gold mine on the Lihir Island which is located about 700 Kilometer northeast of the national capital, Port Moresby, Papua New Guinea has geothermal potential which has been utilized to make Geothermal power plant. The mining activities are still in continuation on the island whose energy requirement are fulfilled by the 56MW geothermal power plant.

Figure 68: :Geothermal power plant at a gold mine

Source: https://www.geothermal-energy.org/pdf/IGAstandard/WGC/2005/0136.pd

The first power plant was commissioned in April 2003, which had a capacity of 6 MW. The drilling campaigns was done from 2000-2003 to complete the medium depth depressurization wells and some dewatering wells. The study successfully found a highly productive zone at depths of 500-600 m BSL, where the temperatures reached about 240-250 degree Celsius. It is because the Papua New Guinea lies in a region which has complex and active tectonic region of numerous plate boundaries, several microplates, and many areas undergoing active deformation. Further feasibility study was conducted over time and another 30 MW plant was commissioned in 2005 and another 20 MW was commissioned. The electricity generated is consumed on the island by the gold mine, in its processing plant and the camps and building set up for the purpose of mining.

This plant was one of the first to start the carbon credits in Papua New Guinea and has been helping the mine company to offset carbon footprint and since the island is not connected to any major electricity grid, it is helping the company to fulfill their energy demands in a sustainable way.

A geothermal power plant was developed in Florida canyon mine in Nevada. This power plant worked on the Organic Rankine Cycle generating power upto 75 kW. This plant was functional from 2013 to 2014 and was closed due to some operational issues and irregular supplies of water to power the system[235].

14.2.2. District Heater in Asturias, Spain[236]

Geothermal energy can also be utilized to heat buildings or to heat the water supply in the local areas or commercial buildings. One such project was done in Asturias, Spain where a geothermal mine water district heating project was completed. The Asturias coal mine had water flooded into the mine making it a reservoir for geothermal energy.

This project was started with establishing a 4MW in 2006, initially two facilities were set up to provide heat or cold to two buildings that were the Vital Alvarez Hospital and the Research Building of the University of Oviedo on the Barredo campus. These two facilities worked perfectly fine and therefore a third facility was added for the headquarters of the Fundacion Asturiana de la Energia (FAEN). These three facilities added up produced a total power of 4 MW. These projects along with technological advancements made it possible for the developers to set up another plant of 2 MW and design a district heating plant giving heat and cold to more buildings. This took the total capacity to 6 MW.

Initially developed as plants focused for 2 building it grew up as a geothermal heat network which can supply energy to multiple buildings, helped people to reduce the load on their electricity from the grid and decrease their expenses. This project of 6 MW will prevent the emission of carbon dioxide up to 636 tons per year, along with giving employment to local people.

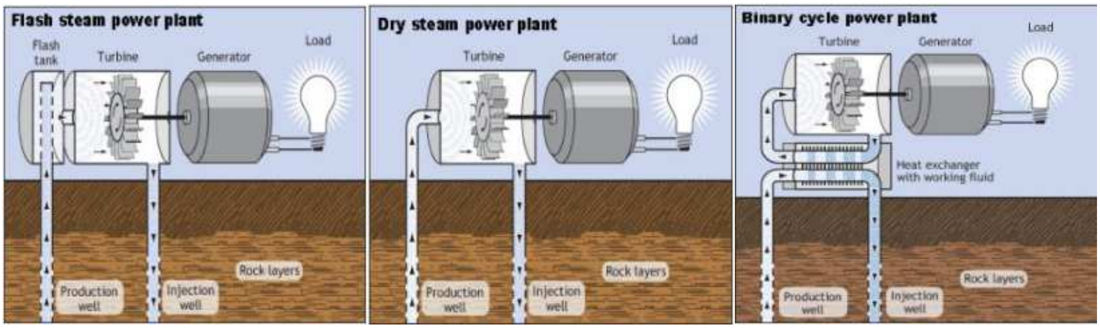
There are several other cases of district heating and geothermal heat pumps which have been developed around the world. Like the heat pumps in the Heerlen, Netherlands which is one of the largest abandoned mine lands geothermal systems with heating power of 700 kW and uses the mine water ranging from 16 °C to 28 °C. Another heat pump on the abandoned coal mine is in the Springhill, Nova Scotia, Canada. This plant has a heating capacity of 111kW and cooling capacity of 160 kW[237].

14.3. Working principle of technology

Geothermal power plants are of three types:

- **Dry Steam Power Plant**: The steam from the bore holes is used directly to turn the turbines which rotate the generator to generate electricity. These plants use very hot steam (>235 °C) and the water generated due to condensation of the steam is injected back into the ground through injection well.
- **Flash Steam Power Plant:** These power plants use the high-pressure water (>180 °C) which is pumped into the turbine chamber, when the pressure is released, the water converts into vapor which is then used to turn the turbine which rotates generator to generate electricity. The water which does not converts into steam and the condensed water is re-injected through the injection well into the geothermal reservoir.
- **Binary Cycle Power Plant**: This power plant uses a secondary fluid to generate electricity. The moderate temperature water from the geothermal reservoir is utilized to heat and vaporize another fluid, with lower boiling temperature, which is then utilized to turn the turbine and thus generate electricity. The water is reinjected into a geothermal reservoir.

Figure 69 https://www.eia.gov/energyexplained/geothermal/geothermal-power-plants.php



Source: https://www.eia.gov/energyexplained/geothermal/geothermal-power-plants.php

Other than these power plants geothermal energy is also utilized as heat pumps and space heaters which utilize the concept of heat exchangers and heat pumps to heat/cool the water and air whichever is required.

14.4. Conditions determining suitability of technology

Geothermal energy utilizes the heat from the earth's interior which comes from the molten ore and the decaying radioactive elements in the interior of the earth. This heat is utilized in various ways to either generate electricity or to heat/cool the water or air. Conditions suitable for setting up a geothermal power plant are[238]:

- For setting up a power plant, the temperature of water should be greater than 175 °C or it should be high-pressure steam.
- It is favorable to have a transmission line or a grid nearby to supply the power.
- For setting up district heaters or geothermal heat pumps, lower temperatures of 20 °C can also be useful.
- District heaters and geothermal heat pumps can also be set up at places where there is no water, i.e., by utilizing the heat energy from the ground soil at depth.

14.5. Potential for symbiosis with other repurposing options

Table 45: Potential symbiosis with geothermal energy

Repurposing options	Degree to which options can be combined
Pumped Underground Storage Hydropower	Geothermal energy provides a continuous power source, and PUSH can store excess energy during low power demand. During increased power demand, water is released from the upper reservoir to the lower one generating electricity to meet the need. The integration provides an eco-friendly energy generation option.

Source: PwC Analysis

Detailed analysis of symbiosis of geothermal power with other repurposing options has been summarized in Section 26.

14.6. Potential environmental impact locally and GHG emission reduction potential

Geothermal energy is a clean and sustainable source of energy. It requires relatively less area of land as compared to other renewable resources of energy and therefore it greatly minimizes the amount of solid waste. Furthermore, it has very minimal impact on the environment as the production of electricity is very silent, and it requires less space. Geothermal energy does not produce any combustion gases and does not leave any chemical residue. The geothermal heat pumps specially have very less impact on the environment as they make use of very shallow resources which are within few hundred meters. Also important to note here is that Geothermal power plants emit ~97% less sulfur compounds and ~99% less carbon dioxide than fossil fuel power plants of similar size[239]. The re-injection of the water into the reservoir however may pose some threat to the locals at it causes vibrations and seismic activities in the ground, but it is said that the injection rate and amount is small that the vibrations and seismic activities can be ignored[240].

14.7. Employment effects

Geothermal power plants employ about 1.17 person per MW for operating the power plants. And these jobs last for the whole lifetime of 50 years or more. Geothermal energy employs more than 2.13 person per MW for the governmental, administrative and technical related jobs. The construction of geothermal energy employs around 3.1 person-years per MW also it employs about 3.3 person-year per MW[241] for the works of manufacturing the machines and its parts[242,243].

14.8. Economic feasibility analysis

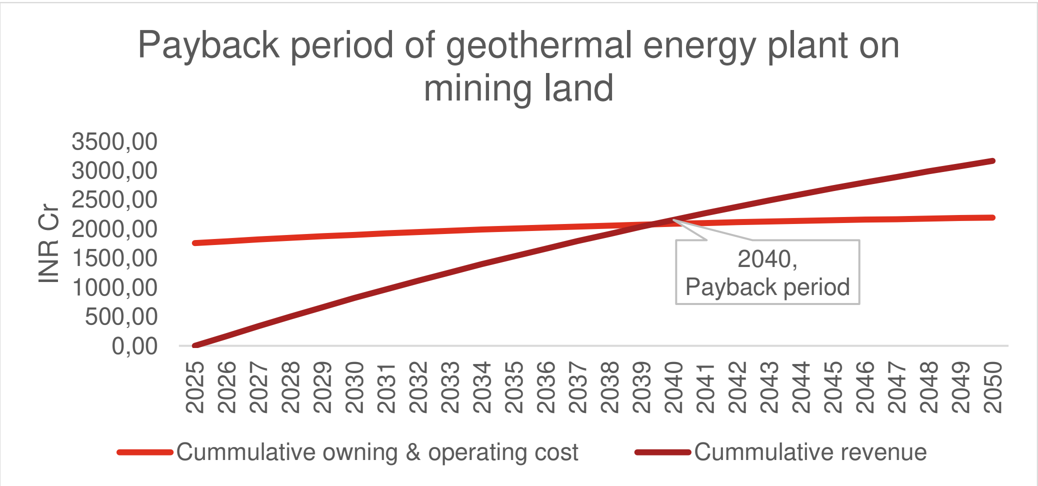
We have prepared an economic model based on the installation of geothermal energy power plant on abandoned mining land for which assumptions taken are tabulated below.

Table 46: Assumptions for economic model of geothermal energy generation at mine site

S.No.	Parameters	Value	Remarks
1	Size of project	38 MW	
2	Life of project	25 Years	
4	Capital cost	1759 INR Cr	PwC Analysis
5	Opex	36.50 INR Cr	PwC Analysis
6	Escalation on Opex	2%	PwC Analysis
7	Electricity produced	332.88 million kwh	PwC Analysis
8	Selling price of electricity	5.82 INR / kwh	PwC Analysis
9	Escalation on selling price	5%	PwC Analysis
10	Discount rate	8.00%	

Source: PwC Analysis

Chart 5: Payback period of geothermal energy project on abandoned mining land



Source: PwC Analysis

14.9. Pros and cons

Table 47: Pros and Cons of geothermal energy

Pros	Cons
Enhancing the RE portfolio of the state: Setting up of geothermal plants will help the state to diversify the portfolio and help them to meet their national ambitions which makes it more predictable and plannable.	**High up-front costs:** Geothermal energy is costly as compared to other source of energy, developments are still going on to make it competitive to other sources.
Round-the-clock supply: Geothermal energy can produce electricity round the clock i.e., it does not have the intermittent nature like solar and wind energy and so is better over them.	**Local vibrations:** As the water is being re-injected into the ground, it may cause vibrations or seismicity in the ground in nearby locality, but since the injection volume is less therefore probability is very less.
Less space: It occupies less space and thus the rest of the space can be used for that purpose too.	**High maintenance:** The mine water contains chemicals and so the plant will require regular maintenance and service to keep the machines working.
Economic development: Communities can fulfill their energy needs and also, they can make use of the heat pumps to reduce the load on electricity grid while fostering the local development by promoting manufacturing of parts and local jobs.	**Location specific:** Geothermal energy is very location specific it requires areas with specific temperatures.
Increased revenues: A state's and municipality's tax revenue may increase as of variety of stakeholders are involved.	
Long Lasting and safer: The geothermal plants have life spans of around 80-100 years on an average, which is higher than other source of energy. Also, since no fuel is involved therefore, they are safer than the traditional plants.	

Source: PwC Analysis

14.10. Suitability for India

Singareni Collieries Company Limited announced its plans to set up a small pilot geothermal power generation unit, of 20 kW capacity, in Pagideru village, Manuguru area, Bhadradri district located in the Telangana[244].

Setting up geothermal energy in mines is still in a progress phase, and the process can be speed up with required technologies, incentives and policies in place.

Proposed MNRE support for Geo-thermal Energy[245]

- Awarding suitable area of land to develop the project and maintain production wells, thus securing commercial viability of the project. Government shall provide land on lease at prices charged to government departments.

- Soft loans might be made available at concessional rate as applicable in other RE technologies through IREDA to support exploration activity.
- The Agency is entitled to carbon credits acquired through geothermal heat utilization/electricity generation.
- Encouraging involvement of foreign entities to explore and develop geothermal resources, provided the foreign collaboration is tied up with technology transfer as 100% FDI is allowed in Renewable Energy Sector.
- The Ministry of Finance will provide 80% depreciation for installation of heat pumps in the first year of installation. These are energy saving devices under wasted heat recovery equipment. To encourage geothermal projects in the country, the Ministry has proposed to the Finance Ministry for revenues ruling in regard to import, excise relaxation and tax benefits on equipment and machinery that are required for initial set up of geothermal heating and cooling projects including geothermal heat pumps and geothermal power generation projects.
- The level of funding is decided on a case-by-case basis. Major thrust would be given through research and development, policy to innovation, and demonstration in the area of geothermal power generation and geo-exchange pumps. The funding that has been proposed is provided in the table below. The project can get funding up to these levels and the actual funding level that will be provided depends on the detailed evaluation of the project in terms of, acceleration of the development of Geothermal energy in India; administrative and technical compliance; contribution to the development of an indigenous and Indian Collaborative GT industry; ability to overcome technical and other barriers; project management capability and environmental compatibility. Funding for projects which are found technically viable is done through National Clean Energy Funds (NCEF).

The various categories of support that would be provided includ:

- **RD&D Projects (Power):** In this category the Research, Design, Development and Demonstration (RDD&D) of the new technology for the deployment of the Geothermal Energy including its Hybridization with other Renewable Energy (RE) Technology will be considered to initiate geothermal based power generation. The scheme stresses carrying out survey/studies for resource assessment/development of geothermal fields of the country. The power produced in terms of Electrical Units defined by CERC will be incentivized. Under the above programs of the Ministry, Research & Development (R&D), Technology Development, Demonstration Projects and projects on other related activities are submitted to the Ministry for financial support. Such projects are scrutinized in the Ministry for support and approval of the competent authority.
- **Industrial Projects (Power):** In this category the projects comprise of only power production and distribution to the state utilities where revenue generation will be considered. The power produced in terms of Electrical Units defined by CERC will be incentivized as per the scheme.
- **Public Good (Direct Heat):** Project comprising for thermal applications for instance the geothermal fluid can be used for space heating, greenhouse cultivation, cooking etc. in those projects MNRE would facilitate the NGO's, entrepreneurs, Central or State PSU's and other private players.
- **Ground Source Heat Pump:** The basic principle on which the GSHP works is refrigeration cycle. The refrigerant carries the heat from one space to another. The heat pump's process

can be reversed. The earth is the main source and sinks of heat and utilizes constant temperature at 10-300 meters below the earth surface. In winter it provides heat and summers it takes the heat. The heat pumps can be adopted to any kind of building at any place as India has a high potential for direct heat use/GSHP.

The maximum level of support which could be available to each of the category are as follows:

Table 48: Support and initiatives for geothermal energy project by GOI

Project Types	In-principle Subsidy
RDD&D Projects (Power)	**Phase-I:** 50% of Deep Drilling cost and in case of failure it will be converted into grant subject to development of site as direct use geothermal heating/cooling. **Phase-II:** On successfully completion of Phase-I, 30% of the rest balance amount will be given as subsidy.
Industrial Projects (Power)	30% of Capital Cost (Maximum support of 9 Cr/MW).
Public Good (Direct Heating/cooling) Ground Source Heat Pump(GSHP's) or Geo-exchange Pumps	30% of System cost in the form of incentives with maximum support of INR 50,000 /TR for first 300 MWt capacity (Individual plant of more than 100 TR capacity), INR 30,000/TR for next 400 MWt and INR 10,000/TR for last 300 MWt target capacity i.e. 1000 MWt.

Source:https://policy.asiapacificenergy.org/node/2657#:~:text=30%25%20of%20System%20cost%20in,target%20capacity%20i.e.%201000%20MWt.

Considering the working principle of geothermal technology and the conditions determining suitability of geothermal technology, the suitability of repurposed geothermal technology in abandoned Indian mines have been analyzed in detail in Section 27.

15. Comparison of all RE options with coal based thermal power plant

This section presents a comparison between coal based thermal power plants with some other prominent renewable energy options that can be adopted to repurpose the abandoned mine sites. For the purpose of comparison, we have kept the capacity of these plants constant i.e. 210 MW, which is the size of a typical thermal power producing plant in India. The comparison is based on area, generation profile, PLF, capital cost requirement, operating cost, employment and lifespan of the project. Below is the table consisting of the figures for comparison.

Table 49: Comparison table (coal based power plant vs RE options)

Options	Capacity (MW)	Area Required (Ha)	Generation Profile (kWh annual)	PLF (%)	CAPEX	OPEX (per year)	CO_2 Emission	Employment (#)	Lifespan (yrs.)
Thermal	210		1176 million unit	64.15	INR 1932 cr	INR 220.6 cr	1.11 million Tonnes[246]	280	30
Wind	210	105	630 million units	20	INR 1541.4 cr	INR 71.4 cr	6,930 Tonnes[247]	320	25
Solar PV	210	126	140 million units	20	INR 1050 cr	INR 16.8 cr	6,020 Tonnes[248]	400	25
Floating Solar	210	147	350 million units	20	INR 1260 cr	INR 16.8 cr	15,050 Tonnes[249]	420	25
Geothermal	210		551.8 million units	30	INR 9240 cr	INR 191 cr	20,968.4 Tonnes[250]	200	25

Source: PwC Analysis

16. Recreational Parks - As Repurposing option

16.1. Introduction to Recreational Parks

Recreational parks are generally open spaces that are designed for people to gather around, enjoy with friends and family, kids to play around, enjoy nature, and engage in activities like bird watching, fishing, bike riding, camping, hiking, etc. In addition to just being a space for recreational activities, recreational parks promote healthy communities, revitalize cities, generates employment, etc. A few benefits of developing recreational parks can be listed as follows:

- **Clean air**: The pollution level in the cities is increasing at a drastic level. As per Air Quality Life Index numbers, in India, the average particulate pollution has increased by 67.7%[251] annually from 1998 to 2021. There has been a reduction in the average life expectancy rate by 2.3 years for the same time period. Recreational parks can be one of the many solutions to help reduce pollution.
- **Health benefits:** Taking walks, engaging in outdoor activities has various health benefits like, strengthening heart, boosting immunity, preventing heart diseases, reduced blood pressure, cholesterol and inflammation, as well as exercising can lower cholesterol levels and reduce stress. People also experience improved mental, physical and general health. Frequent visits have proven to reduce anxiety and depression.
- **Lowering city temperature:** With increased population, road and building cities are getting hotter. As per Air Quality Index[252], temperature varies with land use, where for downtown it is 80% and for place, where there are parks, it is 35%. Thus, parks and green spaces can reduce the temperature.
- **Conserving wildlife:** Parks act as conservation areas by sustaining nature, as indigenous flora and fauna are planted. The parks attract migratory birds, provides bird watching and animal spotting experiences as well[253].
- **Active and passive recreation activities:** There are various active and passive recreational activities that people can enjoy in these parks. Active recreational activities like football, golf, tennis, etc. and passive activities like camping, picnicking, hiking, nature and wildlife photography, bicycling, etc. are some of the many activities that friends and families can take part together.

16.2. Global best practices with examples

16.2.1. Silver Mines Recreational Area

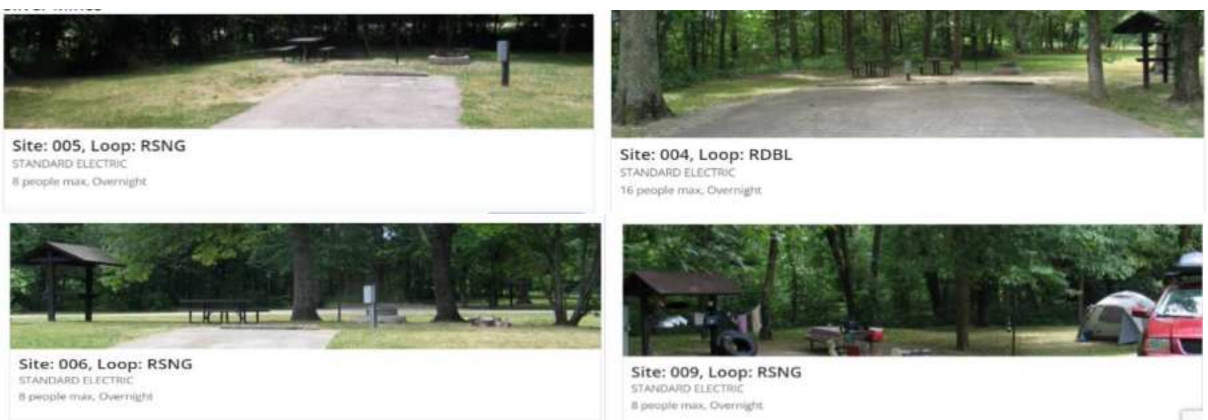
The Einstein Mine is an abandoned silver, lead and tungsten mine which is located near St. Francis River in Missouri. The Einstein Silver Mining company started mining over here from 1877 to 1946, and after 1946, the mining operations ceased completely. The site was converted to Silver Mines Recreation Area, which provides abundant geographical and historical wonders providing various recreational opportunities. The white-water St.

Figure 70: Recreational facilities in shale mine

Source: https://www.ramboll.com/news/transforming-a-former-shale-mine-into-a-new-park-and-outdoor-event-facility

Francis River provides kayaking experience, fishing and hiking opportunities to the visitors. The site is situated near natural attraction spots like Elephant Rocks State Park and Johnsons Shut-ins State Park[254] and has become a tourist attraction spot.

Figure 71: Recreational facilities in Silver mine



Source: https://www.fs.usda.gov/recarea/mtnf/recarea/?recid=21840

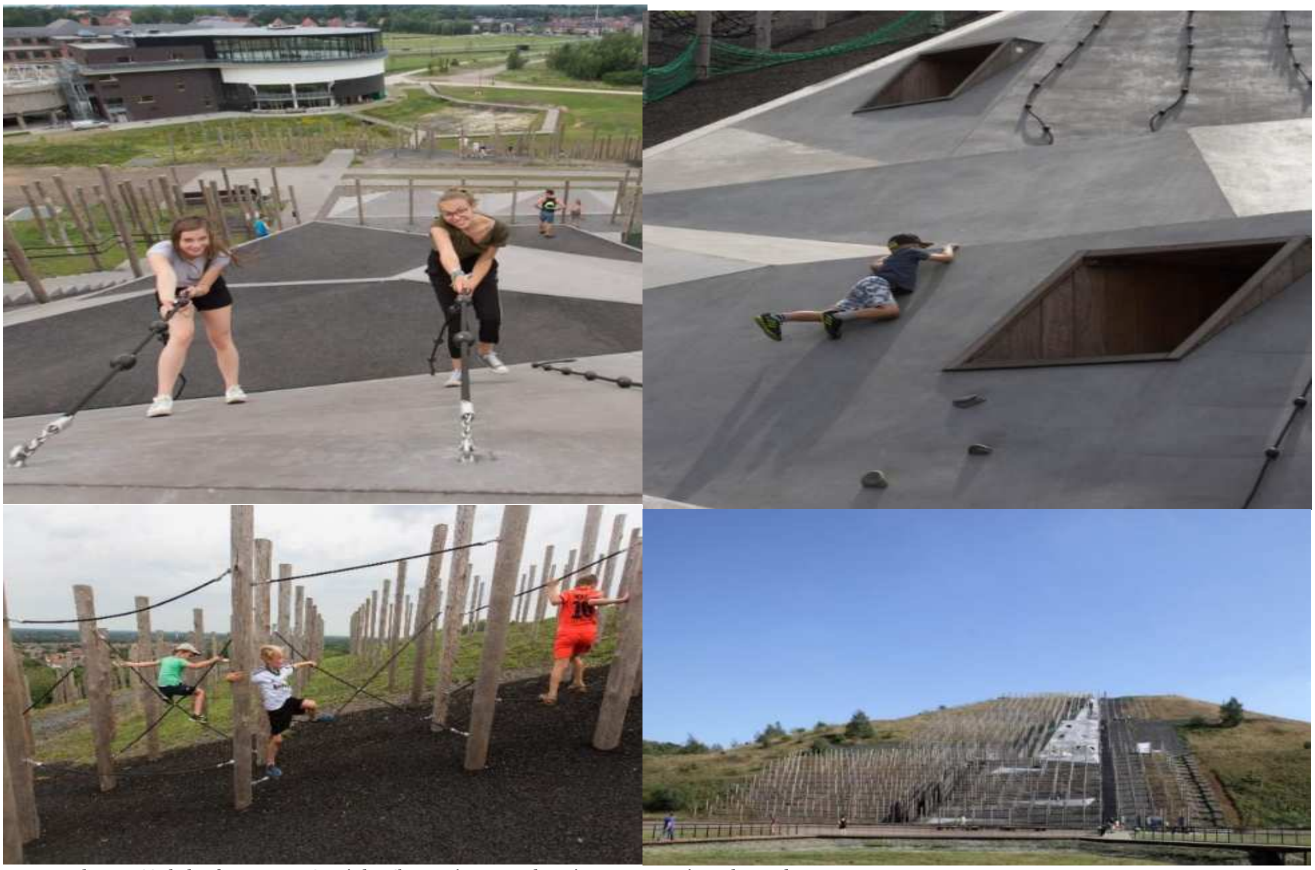
16.2.2. From shale mine to outside venue and park

In Baden-Wuerttemberg, a state of Germany, a 10-hectare shale mining area has been transformed to outdoor event venue and park. The site provides various activities like fossil collection, an open-air amphitheater stage for festivals, concerts, open-air cinema, mining playground, play tower, sound tower, all with a backdrop of visible cement work. The visitors are led through an exhibition path, where there are figures, hand texts signboards, sculptural signs and also provides hands-on activities creating an emotional connect with the visitors[255].

16.2.3. Be-MINE

In Beringen, a city of Belgium, coal mining took place until 1989. Be-MINE, an initiative started by the Beringen tourism board and the municipality, converted the largest industrial archaeological site into cultural sites. The site has undergone a compete redesigning, where Director's Park got converted to public park, the thickening unit transformed to an indoor diving spot, and the power station was redesigned to a climbing hall. The adventure mountain offers various activities like walking, hiking, adventure playground and mountain bike trails for all age groups[256].

Figure 72: Recreational facilities in BE-mine



Source: https://nlplatform.com/articles/be-mine-coal-mine-recreational-park

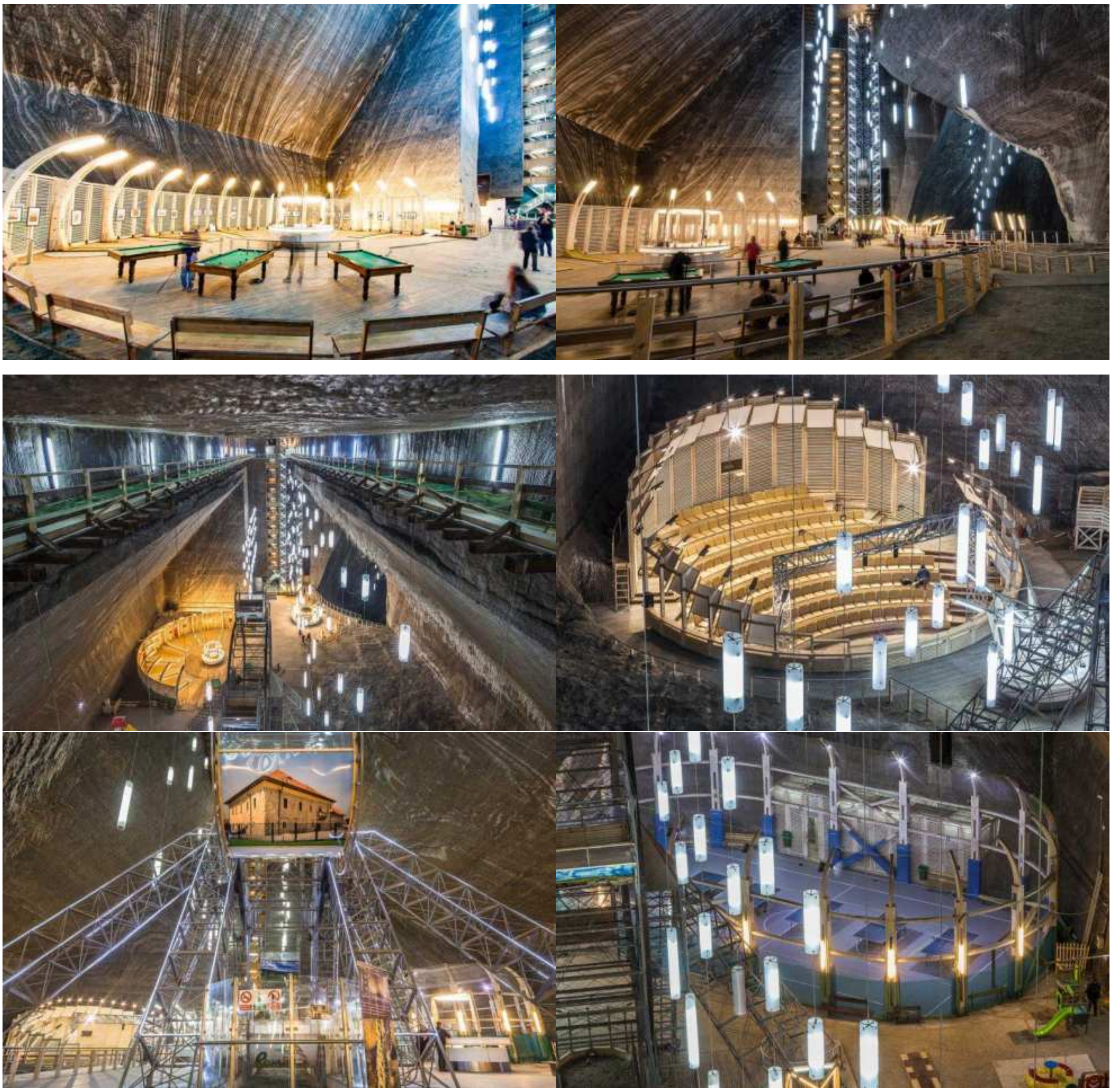
16.2.4. Salt Mine to Amusement Park

Salina Turda is located in Turda a city in Romania has an underground amusement park that its inside one of the oldest salt mines in the world. The mine in 400 feet deep that dates back to the 17^{th} century and after ceasing operations it has been used as cheese storage center, bomb shelter during WWII[257].

The place has now been developed into an amusement park that has a panoramic wheel, mini-golf course, bowling alley, billiards table, sports field, table tennis, playing ground for children, boat ride and a trip to the salt museum. The place also has an amphitheater with heated seats, that regularly host shows and screens movies[258].

Underground amusement park (https://www.youtube.com/watch?v=DkbKZNpauqY)

Figure 73:Salina Turda Amusement Park



Source: https://www.salinaturda.eu/en/locatie/salina-amusement-park/

16.3. Conditions determining suitability of technology

The various conditions that are considered for setting up local parks, recreational parks, theme parks, etc. can be listed as follows:

- **Accessibility** – The park should be set in such a location that people can visit the place with ease. Checking nearest railway stations, airports, metro stations and bus stands as well as ensuring accessibility by public transport and private cars. The higher the ease of access the higher footfall the park will receive.
- **Habitation** – The mines are generally located on the outskirts of cities, thus the habitation is lesser than that of cities. So it should be ensured that there is enough

population living around the region for the park to operate and the location has easy accessibility from nearby cities to attract visitors.

- **Nearby tourist spots** – The location where the park is situated, if there are other tourist spots, historical monuments, any famous sculpture or architecture nearby, it is an added benefit. As generally it is seen that people visiting one tourist spot tend to visit the nearby areas. That is one tourist attraction, leads to increased footfall in the nearby places.
- **Size of land** – Developing any park, be it water park, local park, amusement park, theme park, etc. requires a sizable amount of land. Like a small park require anywhere between 0.5 acre to 2 acres of land and large requires a minimum of 5 acres of land[259]. Availability of such an amount of land is the pre-requisite to setup any kind of park.
- **Power requirement** – Availability of suitability and continuous power source is another utmost requirement to set up parks. As power supply is required for not only lighting up the area, but the rides also consume a lot of power. On an average the daily power consumption by theme parks ranges anywhere between 25,000 kWh to 100,000 kWh[260].
- **Machinery** – The machinery that are required for amusement/ theme/ water parks have very specific design requirement, safety requirements. There are certain India Safety (IS) standards that needs to be followed for chains and wire ropes, conveyor and elevator belts, hydraulic fluid power systems, electrical systems, etc. The details of the required design manufactures, safety measures, etc. can be found here.
- **Architecture** – Considering the type of land, soil in the region, the available flat spaces, slopes, and banks to decide on designing the park accordingly. It should be designed in such a manner that adequate space is provided for rides, recreational areas, vendors, game stalls etc.
- **Disposal system** – Waste disposal is another major factor that should be considered in setting up the parks. Proper disposal mechanisms are very important for maintaining health and hygiene of not only the park but also of the nearby space.

16.4. Potential for symbiosis with other repurposing options

Table 50: Potential symbiosis with recreational park

Repurposing options	Degree to which options can be combined
Ecotourism	Recreational parks increase the green cover of the area attracting different species of animals, birds and insects. Also, the open cast mines carries a history with them. These are the components that forms a ecotourism spot and the visitors can enjoy the nature in its truest form.
Water Storage & Flood Protection	The pits lakes in the recreational mines not only beautify the area but is also beneficial for the park. The lakes provide additional recreational activities to the visitors, like swimming, boating, fishing, etc.
Pisciculture	Recreational parks have water bodies, and a part of it can be used for pisciculture. That will add a new revenue stream.
Memorial / Museum	An underground museum and a recreational park can be set up together. The museum will be present underground and in the above ground area a recreational park can be set up. This will enable the visitors to enjoy both options in one go.

Repurposing options	Degree to which options can be combined
Horticulture	Horticulture ca be incorporated in a recreational park very efficiently. The produce can be used in the various restaurants present in the park. Additionally, it can also become a tourist attraction spot, where the visitors also indulge themselves to learn and understand the concept of horticulture.
Thermal Energy storage	Thermal can be used to for various purposes in a recreational park, like providing lighting, signposts, information kiosks, pergolas, Electrical vehicle charging stations, Solar-powered Trash Compacting Facilities, Energy for furniture and buildings on the area, etc.[261]

Source: PwC Analysis

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or a wildlife sanctuary can be a part of eco-tourism. The infrastructure need and requirement of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar.

Detailed analysis of symbiosis of recreational park with other repurposing options has been summarized in Section 26.

16.5. Potential environmental impact locally and GHG emission reduction potential

There are a number of environmental benefit that parks provide in the region it is located. In any kind of park, plants, trees, flora and fauna are planted. It does not only provide beatification of the area but also helps in conserving nature as well as tackle the greenhouse gas emissions.

Some of the benefits are as follows:

- **Green infrastructure:** The green spaces conserve the natural ecosystem, its values, its functions, ensures cleaner air, sustains wildlife, acts as community's natural life support, provides economic and environmental sustainability.
- **Smart Growth:** Urban parks broadly consist of parkland, landscaped boulevards, public gardens and waterfront promenades. Parks are not just venues for fun, enjoyment and games but the open spaces, form a breathing room of neighborhood and cities. And on economic front parks also improves real estate value, and civic culture of the communities[262].
- **Water conservation:** Tree and grass are considered the most efficient and cost-effective method to conserve water. The unpaved ground in the parks helps in collecting the rainwater, improving underground water level as well as is an effective mechanism to manage storm water.
- **Reducing urban heat:** The roads, vehicles, and buildings in the cities are one of the major reasons for rising temperature, as compared to other lands. The parks, the trees planted in the park, help in reducing the temperature of the area, making the cities comparatively cooler.
- **Cleaner air:** Plants and trees help in removing pollutants from the air. Among the various pollutants that can be found in the air, pollutants of greenhouse gas emission are also

present, which also leads to rising temperature in the cities. Thus, the parks also help in reducing pollutants and GHG effect in the city[263].

16.6. Employment effects

As per The Economic Impact of Local Parks provided by Local Park and Recreation Agencies on the U.S. Economy, for the year 2019, the recreation agencies and the local parks had generated 1,280,724 jobs that provided salaries and wages. More the 385,000[264] (part-time and full time) people were employed in more than 10,000 recreational agencies and local parks.

According to Indian Association of Amusement Parks and Industries (IAAPI) President Ajay Sarin, in 2018, the industry provides direct employment to around 80,000 people and indirect employment to 1.5 lack people[265]. With the onset of COVID-19, the amusement parks were shut down that affected both direct and indirect employment severely.

In Pune, the IAAPI had requested the chief of the state to reopen the entertainment parks with 50% capacity, as the state itself has more than 37 entertainment parks, that provided 13,000 and 52,000 direct and indirect employment respectively.

Following is the list of few recreational parks, that provide numbers related to the area covered and direct employment provided by them respectively[266].

Table 51: Area and direct employees of recreational park

Recreational Park	Size (acre)	Direct employment
Imagica	138	552[267]
Wonderla	110	627[268]
Nicco Park	40	216[269]
Ramoji Film City	1,666	6000[270]

Source: PwC analyses of sources mentioned in the references

16.7. Economic feasibility analysis

A large plot is required to set up recreational parks which can range from 5 acres to 100-200 acres. Thus, a large amount of money is involved in setting up an amusement park in India. In smaller cities it might range from INR 1-1.25 crore per acre to larger projects which might cost INR 100 – 1,500 crores. The cost of equipment and rides varies from around INR 20,800 - INR 32,000 for a single Ferris wheel to INR 445,000 for a 10-seater roller coaster.

In addition to the mentioned cost, there are numerous legalities that needs to be followed before setting up, like permits, safety checks, safety regulations, government permissions, food license, license from Public Work Department (PWD), No Objection Certificates from fire department, pollution control center, etc.[271]

The amusement park business has some associated cost with it, which can be listed as follows:

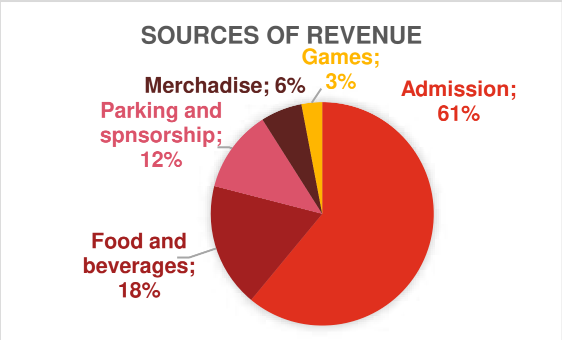
- **Maintenance cost:** The park needs to maintain the property and rides to ensure they are in good condition so that they can be operated for a long time period.
- **Human resource:** The park needs to pay its direct permanent employees, and also must incur related cost like, insurance, health coverage, etc. to ensure that employees are motivated to work there.
- **Shops:** Amusement parks have gift shops where they sell merchandise and souvenirs. As well as various game stalls and restaurants are also set up for visitors to entertain themselves.
- **Taxes and insurance:** There are numerous liabilities that the amusement parks have to incur, like land tax, property tax, licensing, insurances, safety checks, etc. which form a large part of the costs that are incurred by these amusement parks.
- **New rides:** After a certain point, the parks have to come up with new rides and attractions to attract more visitors, to increase their revenue[272].

16.7.1. Revenue generations

The main source of income of recreational park comes from admission in the park, followed by parking, sponsorship, food and beverages, merchandise and games. Of the total revenue earned by the amusement parks, the share percentage contributed by each of the source can be found in the figure[273].

The following table lists few of the amusement parks, and contain details about the footfalls they receive, their ticket prices, and revenue they have generated.

Figure 74: Percentage share of each revenue



Source: https://www.goodfellowpublishers.com/free_files/Chapter%2010-

Table 52: Footfall and revenue earned by recreational park in FY 23

Recreational Park	Footfall(lakh)	Total Revenue (INR Lakh)
Imagica	13.6	33,374.36[274]
Wonderla	33	46,000[275]
Nicco Park	14.45	7,904[276]

Source: PwC analyses of sources mentioned in the references

We have prepared an economic model based on setting up a recreational park on abandoned mining land for which assumptions taken are tabulated below.

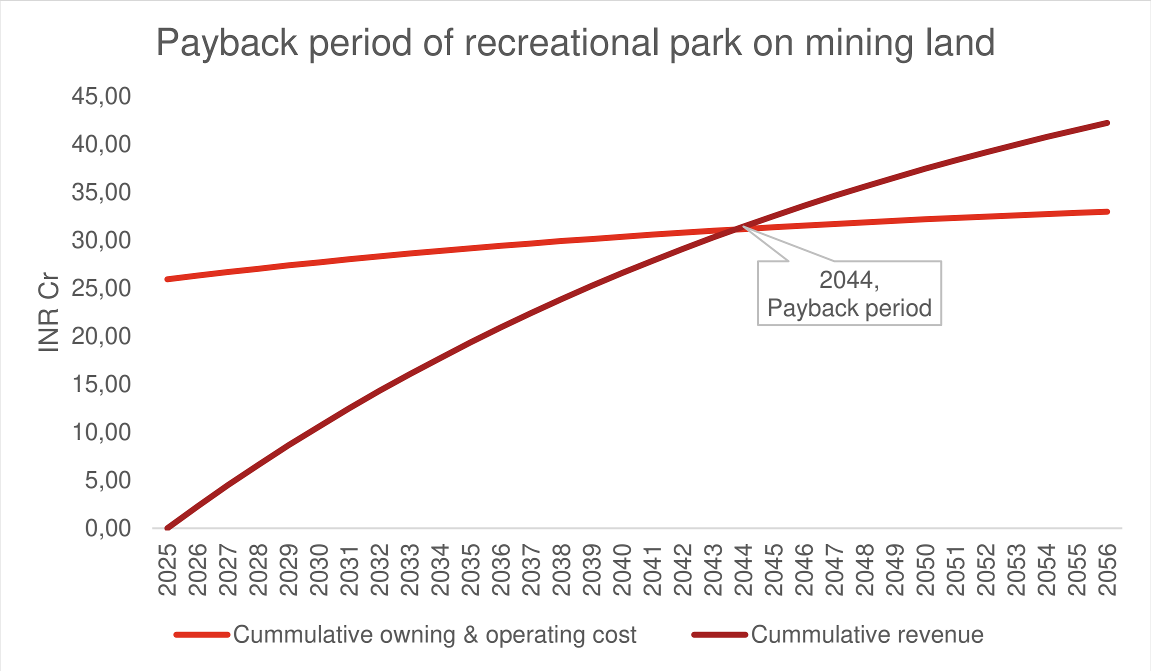
Table 53: Assumptions for economic model of recreational parks on mining land

S.No.	Parameters	Value	Remarks
1	Area for repurposing	10 Ha	
2	Life of project	30 Years	

S.No.	Parameters	Value	Remarks
3	Capital cost	24.7 INR Cr	PwC Analysis
4	Opex	0.42 INR Cr	PwC Analysis
5	Escalation on Opex	2%	PwC Analysis
6	Entry tickets sold per day	300	
7	Cost of one ticket	200	
8	Number of shops	30	
9	Rent per shop per year	2,40,000 INR	
10	Revenue generated	2.52 Cr	
11	Discount rate	6%	
12	Working days in a year	300	

Source: PwC Analysis

Chart 6: Payback period for recreational park



Source: PwC Analysis

16.8. Pros and cons

The different advantages and disadvantages of setting up recreational park are as follows:

Table 54: Pros and Cons of recreational park

Pros	Cons
Healthier community: The parks provide activities like hiking, bike riding, provide space for running, jogging, etc. improving the health of the visitors.	**Crowded place:** The parks are generally overcrowded during the session, which makes the visitors not able to enjoy their outing at all.
Outdoor activity: The screen time of children has increased drastically. They are either using phones, tablets, computers or playing games on their gaming consoles. The parks play a vital part in improve this.	**Unsocial activities:** As the parks are overcrowded, there has been many complaints of unsocial activities that the visitors have to go through, like pickpocketing, theft, harassment, etc.
Improving mental health: Parks are a place where people go out with friends and families to relax. Spending time and engaging in activities with them helps to release their stress and brings change in their daily life routine.	**Dangerous rides (musement parks):** There has been many numerous news of how children have suffered injuries in certain rides, and their safety has been put at stake.
Job creation: Parks a generates lot of earning opportunities. There are direct employees to administer the parks. There are indirect employees, who runs food and beverage stalls, game stalls, small petty shops selling daily need products, etc. And in addition indirect and induced shops that are providing infrastructure, hotels, and transportation of guests and products to the parks.	**Safety measures:** For cost cutting these parks can use low quality equipment, overlook safety checks, leading to severe injuries to the riders.
Healthier air: Trees in the parks remove tons of toxins that are present in the air. Improve natural ecosystems, reduces city temperature, reduces pollution, etc.	

Source: PwC Analysis

16.9. Suitability for India

As of now recreatioal parks haven't been set up on mines in India, but plans can be made for the same. Though there needs to be stringent quality checks to be made for the safety and security of the incoming visitor and to ensure that these remain operational for a longer time period. For efficient working there should be proper policies and incentives in place, that ensures amusement parks set up on a mine can operate with all the safety measures in place.

Considering the conditions determining suitability of recreational parks, the suitability of recreational parks in abandoned Indian mines have been analyzed in detail in Section 27.

17. Ecotourism - As Repurposing option

17.1. Introduction to repurposing option

The International Ecotourism Society or TIES defines ecotourism as "responsible travel to natural areas that conserves the environment, sustains the well-being of the local people, and involves interpretation and education [both in its staff and its guests].[277]"

According to United Nations World Tourism Organization (UNWTO[278]), the following characteristics needs to be there in a tourism to be called ecotourism:

- It is a nature-based tourism where the main attraction for the tourists is to observe and appreciate nature and its prevailing traditional cultures.
- It must have interpretation and educational features.
- Organized by specialized tour operators for small groups.
- The service providers are generally small and are run locally by business owners.
- Minimizes the negative impacts on the socio-cultural and natural environment.
- Maintains natural land and nearby areas attract tourists to undertake ecotourism.
- Generates economic benefits for the communities, organizations and the authorities that manage natural areas for conservation purposes.
- Providing income opportunities and alternative employment for the local communities.
- Increased awareness towards conserving the natural and cultural assets, by both the tourists and the locals.

17.2. Global best practices with examples

17.2.1. Jhanjra Eco-Park

Jhanjra eco-park has been developed on a 4.5-hectare area, with the aim to provide an eco-friendly and healthy environment to the community. The park has orchards, medicinal plants, ornamental plants, and an open-sky gym, for the local community. It would also have a lawn, a water body, play zone for children, gazebos, parking zone, rest shelter and a Japanese garden that will have walking pathways, pagoda, bridge, pergola, etc.

Figure 75: Proposed design and facilities at Jhanjra Park

Source: https://easterncoal.nic.in/media/CTB_Green-Mining.pdf

17.2.2. Gunjan Ecological Park

Ratibati colliery was an open-cast mine, which was abandoned in mid1980s, as it faced waterlogging related issues, as well as the coal seams was also exhausting. Gunjan park is developed on that abandoned mine. The quarry has been transformed into a small lake that has an island amidst the lake. The lake is surrounded by a small heap which was formed as a result of accumulation of mining dumps. During rehabilitation program after closing of the mine, plantation was attempted covering the heap portion. Now, it is a popular picnic spot for the local people. An amusement park (named Gunjan park) has been developed recently[279]. The aesthetics of the park attracts not only tourists, but birds, insects and animals as well. Many birds are native to the park and enhances the beauty of the park. The park is spreads across 19.5 hectares and includes a ~5 hectares water body[280].

Figure 76: images of Gunjan Park

Source: https://easterncoal.nic.in/media/CTB_Green-Mining.pdf

17.2.3. Mudwani Dam Eco-park

The Mudwani Dam eco-park is located in Singrauli, Madhya Pradesh, has a beautiful waterfront, sports area for children, walking pathways, and shops, and restaurants selling local products. There is a seating area at the waterfront, that provides a view of the lake to the tourists, where they can relax and enjoy the view. The park has various environmental

Figure 77: Glimpses of Mudwani Dam eco-park

Source:https://www.psuconnect.in/news/ncl-develops-mudwani-dam-eco-park/33588/, https://pib.gov.in/PressReleasePage.aspx?PRID=1888060 benefits, like preventing soil erosion, refines and purifies the air, ensures ecological development, etc.

17.3. Conditions determining suitability of the technology

- **Resource mobilization** – The main focus of eco-tourism is locals are the key stakeholders. And since the coal mines are situated at a place far off from cities, it is ideal to set up ecotourism spots. And since the locals are the main players, central government will provide participatory frameworks encouraging resource mobilization by the stakeholders to develop, operate and maintain the eco-tourism zones ensuring equitable benefits flow from eco-tourism accrues. And since most of eco-tourism sites are located in remote places and are predominated by small-scale operators, the central government may take up suitable programme to facilitate the operators for accessing incentives, in a timely and adequate manner, that are allowed to the tourism sector[281].
- **Accessibility** – The eco-tourism spot should be easily accessible so that people can visit the place with ease. Checking nearest railway stations, airports, metro stations and bus stands as well as ensuring accessibility by public transport and private cars. The higher the ease of access the higher footfall it will receive.
- **Habitation** – The mines are generally located on the outskirts of cities, thus the habitation is lesser than that of cities. So, it should be ensured that there is enough population living around the region for the park to operate and the location has easy accessibility from nearby cities to attract visitors.
- **Nearby tourist spots** – The location where the spot is situated, if there are other tourist spots, historical monuments, any famous sculpture or architecture nearby, it is an added benefit. As generally it is seen that people visiting one tourist spot tend to visit the nearby areas. That is one tourist attraction, leads to increased footfall in the nearby places.

17.4. Potential for symbiosis with other repurposing options

Table 55: Potential symbiosis with ecotourism

Repurposing options	Degree to which options can be combined
Water Storage & Flood Protection	Developing pit lakes for ecotourism helps to provide a holistic view of the ecosystem that can thrive in the mines. Providing tours to visitors will help them understand the importance of conserving nature.
Memorial / Museum	Adding museums in the ecotourism also provides a complete educational tour to the visitors. It showcases how things were done in the bygone years and how conservation is carried on in the present, providing a single place were past meets the present.
Thermal Energy storage	Thermal can be used to for various purposes in a recreational park, like providing lighting, signposts, information kiosks, pergolas, Electrical vehicle charging stations, Solar-powered Trash Compacting Facilities, Energy for furniture and buildings on the area, etc.[282]

Repurposing options	Degree to which options can be combined
Floating Solar	Floating solar farms can be set up with or in ecotourism and that brings the following benefits with the set up. • Utilizing water surfaces efficiently for clean energy production. • Increase in electricity generation due to cooling effect of water. • Positive impact on the environment with reduced evaporation and CO_2 emissions. • Attracting visitors with visually appealing and eco-friendly features and creating eco-tourism opportunities. • Enhancing aquatic biodiversity and acting as sanctuaries for birds[283].
Recreational Parks	Recreational parks increase the green cover of the area attracting different species of animals, birds and insects. Also, the open cast mines carry a history with it. These are the components that form ecotourism spots and the visitors can enjoy the nature in its truest form.
Pumped Storage Hydropower	Integrating ecotourism and PSH can bring sustainable energy practice while preserving nature. The reservoirs add picturesque view, the visitors can visit the areas and understand how the system works whilst enjoying hiking and observing the wildlife.

Source: PwC Analysis

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure need and requirement of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar.

Detailed analysis of symbiosis of ecotourism with other repurposing options has been summarized in Section 26.

17.5. Potential environmental impact locally and GHG emission reduction potential

The complete focus of eco-tourism revolves around the fundamentals of environmental awareness, conserving nature, empowering and providing economic benefits to the locals.

- **Protecting local culture:** Visitors learns to respect the indigenous people and their local culture, understands the importance to protect the natural treasures and are encouraged to conserve the biologically diverse areas with the cultural zones.
- **Minimize environmental impact:** When the ecotourism tours are planned properly, it reduces the adverse impacts as the visitors get a different perspective to save the environment and are encouraged to preserve nature. It also promotes using natural resources responsibly, limits energy consumption, uses renewable energy, etc. that reduces any further damage to the ecosystem.
- **Preserving endangered animals:** Ecotourism spots attract different species of birds, animals and insects, as most of their habitats are being destroyed by humans for development purposes. As a reason quite a few species have gone extinct, and many are on the verge of going extinct. In such a situation, the spots help in preserving their population[284].

- **Reduced greenhouse gas emission:** Eco-tourism encourages sustainable transportation like cycling and walking instead of driving cars. Cars emits harmful emissions, whereas these transportations reduce the carbon emission, thus directly reducing the greenhouse gas emissions, ensuring overall reduction of any negative impact on the environment[285].

17.6. Employment effects

Ecotourism benefits local communities by creating jobs, providing income opportunities and boosting the economy to conserve natural resources. There are various different job opportunities that are available for the locals like tour guide, reservation agent, park ranger, animal carer, naturalist, resort manager, wildlife specialist, etc. According to a management plan of Chinnar Wildlife Sanctuary for 2012-13 - 2021-22 there are 39 sanctioned staff[286].

17.7. Economic feasibility analysis

In India, in the recent years a few abandoned coal mines, across different states, have been converted into eco-parks, and there are few that are proposed to be developed or are under construction. The fund that has been allocated for each of the completed and upcoming/ongoing eco-parks can be found in this link. Listing down a few as follows:

Table 56: Fund allocation for eco-parks

Eco-parks set up in last 5 years	Funds allocated (INR lakh)	Eco-parks to be set up	Funds allocated (INR lakh)
Kenapara Eco Park,	197	**Manikpur Eco- Park**	1,111
Modwani Dam Eco Park	400	**Eco Nature Park**	2,464
Mine-I Eco- Park	328.21	**Dhori Eco-Park**	1,233
Bal Gangadhar Tilak Eco Park	255	**Piparwar Eco-Park**	909
Mine-II Eco- Park,	287.82	**Hazaribagh Eco-Park**	1,196

Source: https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1947002

The source of revenue for these eco-tourist spots is mainly dependent on number of visitors that visit the spots. The ticket price for Eravikulam National Park ranges from INR 200 for Indians INR 500 for foreigners, and additional charges for normal cameras, video camera, reservations etc.[287] Last year during the Diwali time 2,400 to 3,908 per day[288].

The economic model of this repurposing option is similar to the recreational park as the main source of income will be from the entry tickets, activity charges and shop rent.

17.8. Pros and cons

There are various advantages and disadvantages of setting up a ecotourism spot, some of which are as follows:

Table 57: Pros and Cons of ecotourism

Pros	Cons
Employment: The ecotourism spots employ locals to maintain, administer, and ensure seamless operation of the ecotourism spots.	**Undesirable and unwanted social change:** When a lot of tourists starts to visit a particular spot, they tend to destroy the place, and the place losses its identity.
Preserving nature and heritage: The aim of ecotourism is to educate the visitors the importance of conserving the environment and ensure well being of the locals.	**Sense of antipathy:** Even though locals are employed, but they get a small portion of the total revenue. The larger portion is enjoyed by the organizers.
Development of the area: Ecotourism boost development of the nearby areas. Infrastructures like hotels, health care facilities, transports are developed to host the visitors.	**Effects on environment:** For developing the area trees are cut, and as tourist increases large scale deforestation happens, as well as waste disposal by tourists also increases[289].
Promoting stability: Ecotourism generates employment, creates environmental awareness, improves economy, and ensures cross-culture awareness.	

Source: PwC Analysis

17.9. Suitability for India

As mentioned above numerous mine sites have already been transformed to eco-tourism spots, and there are more such spots that will be transformed completely in the coming years.

Considering the conditions determining suitability of eco-tourism, the suitability of eco-tourism in abandoned Indian mines have been analyzed in detail in Section 27.

18. Museum - As Repurposing option

18.1. Introduction to repurposing option

Museums are institutions dedicated to collecting, research, conserve, exhibit and interpret tangible and intangible things, which are historical and has cultural importance. These are exhibited to the public so that they get a glimpse of what the past looked like, how things were in the previous centuries, how a certain establishment worked when it was operational. It exhibits the creativity of people and civilizations from the past, hence linking the past and the present.

The public can visit underground coal museums to get to know how the coal mines worked, what was the life of a coal miner, and in the bygone years, when there were inadequate lightening options, how they conducted their daily routines.

People comes face to face with many experiences like:

- **Demo structures:** They can experience the different tools that were used, the gear that was worn, like boots specifically used for coal mining, cap lamps, underground vintage telephones, etc.
- **Real models:** They also have real but non-operative transformers, circuit breakers, haulages[290], light switches, etc. providing knowledge on the engineering and mechanics that were required to harvest coal.
- **Real life experience:** While going down into the underground, visitors can actually get the feel of what the miners felt. The ride in the cage elevator to get in the mine, boarding work trains to experience their daily commute, using safety lamps to reveal methane gas, etc.[291].

18.2. Global best practices with examples

18.2.1. Museum of Science and Industry (MSI) Chicago

The coal mine museum of MSI has been providing the guests with a tour of the mines from 1933. The tour provides the visitors with a real-life experience of how a miner's life was in the coal mine. It starts with using the mineshaft/cage elevator to go into the mine, experiencing the machineries and methodologies that were used for mining coal, using the work train to explore the mine and knowing how the extraction machines have evolved over the years. The tour provides a sense of the sounds, the rumbles, and the real experience of how it felt working in those mines[292].

Figure 78: Underground mine tour by MSI

Source: https://www.msichicago.org/explore/whats-here/exhibits/coal-mine/

18.2.2. Margherita Coal Mine Museum – Assam

The Indian state, Assam has a wide forest coverage, and large quantities of limestone, low ash coal, dolomite deposits is available. Coal mining is one of the sources of income for the people of the state. The museum houses relics of locomotives that were used, memoirs of WWII, history of Assam railways, cyclostyle machines, real life models of machinery used in the mines, gears and tools used by miners, etc. The coal mine museum depicts how coal

Figure 79: Glimpse of vintage machines used in the coal mine

Source: https://kaziranganationalparkassam.in/coal-museum-margherita-assam/

mining was done with life models, demo structure and necessary equipment required to carry out the mining work[293].

18.2.3. Chatterley Whitfield coal museum

Chatterley Whitfield was the first underground coal mining museum in United Kingdom. The underground tours started in 1977 and in the early years witnessed nearly 40,000 visitors a year. But in 1993, the underground tours ceased, and a new above ground museum was built. In 2019, urban explorers found the remains of the underground museum. The museum had deep mining sites, colliery buildings, shafts, heap steads, rollway lines, etc. it provided a complete experience of coal mines that no other coalfield present in England could provide[294].

Figure 80: Chatterley Whitfield coal mine museum

Source: https://www.europeanheritagedays.com/story/124d6/The-Hidden-remains-of-an-abandoned-Mining-Museum-in-the-UK

Links to few other underground coal mine museums are given below.

Miners Museum

Big Pit

No. 9 Coal Mine & Museum

18.3. Conditions determining suitability of technology

The various conditions that are considered to set up underground museum can be listed as follows:

- **Accessibility** – The museum should be set in such a location that people can visit the place with ease. Checking nearest railway stations, airports, metro stations and bus stands as well as ensuring accessibility by public transport and private cars. The higher the ease of access the higher footfall the park will receive.
- **Habitation** – The mines are generally located on the outskirts of cities, thus the habitation is lesser than that of cities. So, it should be ensured that there is enough population living around the region for the museum to operate and the location has easy accessibility from nearby cities to attract visitors.
- **Nearby tourist spots** – The location where the park is situated, if there are other tourist spots, historical monuments, any famous sculpture or architecture nearby, it is an added benefit. As generally it is seen that people visiting one tourist spot tend to visit the nearby areas. That is one tourist attraction, leads to increased footfall in the nearby places.
- **Materials**: Materials that are used for construction should be selected wisely. Using concrete and steel to support the structure is generally practiced. Ground water level increases humidity, thus using waterproof concrete, asphalt, sheet metals reduce

moisture and designing the interior with facades that permits vapor and vapor absorbing partitions prevent excess moisture[295].

- **Air, ventilation and humidity**: Measures should be taken to ensure proper mechanism is in place to ensure airflow, optimum temperature and humidity, and proper ventilation system is installed, so the visitors can stay, experience the environment, and can interact with each other easily.

18.4. Potential for symbiosis with other repurposing options

Table 58: Potential symbiosis with museum

Repurposing options	Degree to which options can be combined
Recreational Parks	An underground museum and a recreational park can be set up together. The museum will be present underground and in the above ground area a recreational park can be set up. This will enable the visitors to enjoy both options in one go.
Ecotourism	Adding museums in the ecotourism also provides a complete educational tour to the visitors. It showcases how things were done in the bygone years and how conservation is carried on in the present, providing a single place were past meets the present.

Source: PwC Analysis

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure need and requirement of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar.

Detailed analysis of symbiosis of museum with other repurposing options has been summarized in Section 26.

18.5. Potential environmental impact locally and GHG emission reduction potential

Building underground constructions is cost efficient and energy efficient as well. The benefits of energy efficiency can be enjoyed from the beginning of the construction and throughout its operation. Some of the benefits are as follows:

- Since the temperature remains constant underground and is cooler as compared to surface temperature no additional cooling systems need to be installed. Cooling systems like air conditioners are one of the main reasons for global warming, and also one of the factors that plays a role in increased greenhouse gas emission. The natural temperature of the underground construction requires no such setup.
- This also means that the place would provide thermal stability and heat insulation throughout its operation, ensuring stable temperatures with little fluctuation in the temperature at times.

- If through some architectural means natural lighting is provided in the underground construction, the requirement of artificial lighting will reduce drastically.
- If the underground construction is closer to the surface, and has thin soil layer, then green roofs can be constructed, to maintain the temperature underground. It will efficiently reduce rising temperature in summer and decreased temperature in winter[296].

18.6. Employment effects

Museums also provide employment generation opportunities, where people are employed for various jobs, like administration, maintenance, protecting the artifacts and the vicinity, etc. Following provides a list of people employed by few of the museums situated in India.

Table 59: Employment genarated by museums

Museum	Area (sq mt)	Employees
National Museum, New Delhi	10,000	140
Salar Jung Museum, Hyderabad	1,301	112
Indian Museum, Kolkata	930	109
Victoria Memorial Hall, Kolkata	7,154	100
National Council of Science Museum	3,000	850

Source: https://pib.gov.in/PressReleasePage.aspx?PRID=1484462

18.7. Economic feasibility analysis

The Rashtrapati Bhawan has a museum spanned across 1.3 lakh square feet. It is a three-storied building with 2 floors under the ground[297]. It took two years to construct the museum at a cost of nearly INR 80 crores. The museum provides a walk through the British Raj era, freedom movements of India, offices of all the Indian residents, starting from Dr. Rajendra Prasad to current day president and is home to 2,000 artifacts describing the legacy. The tickets are priced at INR 50 for adults and entry is free for children under eight years of age.

To encourage opening up of museums, the government of India is providing financial assistance under Museum Grant Scheme. The details can be found here.

We have prepared an economic model based on setting up a museum on an abandoned mining site for which assumptions taken are tabulated below.

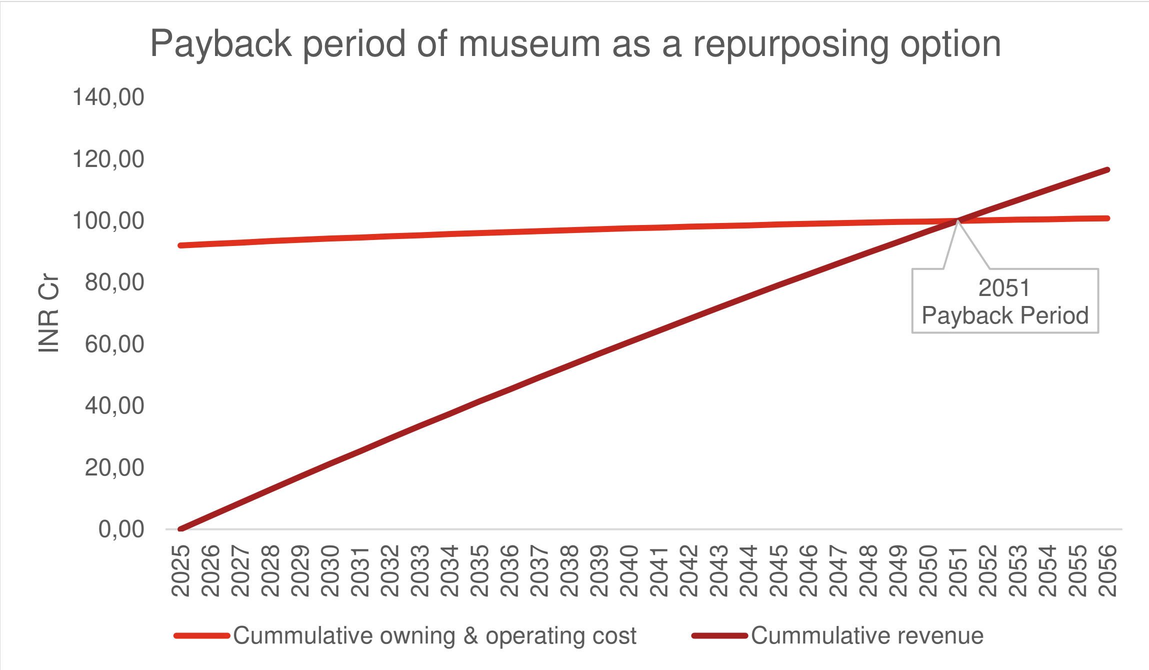
Table 60: Assumptions for economics model of museum on mining land

S.No.	Parameters	Value	Remarks
1	Area for repurposing	10 Ha	
2	Life of project	30 Years	
3	Capital cost	91.96 INR Cr	PwC Analysis
4	Opex	0.53 INR Cr	PwC Analysis
5	Escalation on Opex	2%	PwC Analysis
6	Number of tickets sold per day	300	

7	price of one ticket	500 INR	
8	Working days	300	
9	Shop rental per year	240000 INR	
10	Revenue generation	4.62 INR Cr	
11	Escalation on revenue	5%	
12	Discount Rate	6%	

Source: PwC Analysis

Chart 7: Payback period for museum as a repurposing option on mining land



Source: PwC Analysis

18.8. Pros and cons

The various advantages and disadvantages of setting up an underground museum can be tabulated as follows:

Table 61: Pros and Cons of museum

Pros	Cons
Low maintenance: Rock caverns requires low maintenance as they are stable structures and can withstand high pressure.	**Planning the construction:** Experts needs to be consulted for planning underground construction. Because of the unconventional nature, cautious consultation is required.
Land usage: The above ground is available and can be put to use for something else in case of underground mine museums.	**Special consideration:** Interior designing requires special consideration as the walls are not even.

Pros	Cons
Energy advantage: The temperature remains stable under the ground and provides natural heat insulation.	**Flood:** Flooding is a factor that should be kept in mind while construction any underground constructions
Cost efficient: Underground construction is cheaper, as in conventional building, the costs of foundation, material, structure are in proportion to size of building.	**Ventilation and lighting:** Providing proper lighting in the complex and ensure proper ventilation system might require complex method[298].
Soundproof environment: Underground constructions eliminate above the ground noises leading to improved experience for visitors.	**Safety:** The worked-out area are prone to various types of stress in underground mines and slope stability can become a cause of concern in open caste mines.
Employment generaton and local development: Mueseums would generate jobs and revenues for the areas.	

Source: PwC Analysis

18.9. Suitability for India

The Margherita coal mine museum situated in Assam is one such example where, on a coal mine a museum has been set up. The underground mine is accessible to the visitors to get to know the environment in which a miner would work in those days.

To set up an underground museum, the main point of concern has to be the ventilation system and proper lighting of the facilities.

Considering the conditions determining suitability of underground museums, the suitability of underground museums in abandoned Indian mines have been analyzed in detail in Section 27.

19. Waste Disposal- Bio Reactor Landfill - As Repurposing option

19.1. Introduction to repurposing option

A bioreactor landfill is a landfill where municipal solid wastes are collected and in which moisture is maintained to help bacteria breakdown the waste. Adding liquid and air enhances the microbial process that helps to improve the waste degradation and stabilization process. In a bioreactor landfill, there are different types of bioreactor landfill, aerobic, anaerobic, hybrid (aerobic-anaerobic) and facultative, these types have been explained in the later section.

Figure 81: Time taken by landfills

Soure: https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf

Bioreactor landfill accelerates the decomposition process. In bioreactor landfill the waste decomposes in years whereas in natural decomposition the process takes decades. It accelerates the decomposition process of green waste, food, paper and other waste by providing the condition that is required by the microorganisms to degrade the waste. And to optimize the condition and key factor is to control the moisture content of the waste. The moisture content of the waste needs to be 35-45 percent of the weight. The liquids that can be added are leachate, water, storm water, condense gas, wastewater and sewage sludge[299].

The falling videos provide details on how a landfill works.

[Sanitary landfilling]

[Landfilling process]

19.2. Global best practices with examples

19.2.1. Woodlawn Eco Precinct

Woodlawn was a copper, lead and zinc mine situated in the New South Wales, Australia. Since 2000, a part of the mine has been repurposed and being used as a bioreactor and eco-precinct. In the eco precinct, a circular economy is maintained, with the moto "Let no waste be wasted". The facility includes a Mechanical Biological Treatment (MBT) plant, a bioenergy facility and a bioreactor. The various activities that are undertaken in the facility include,

Figure 82: Woodlawn mine

Source:https://www.veolia.com/anz/sites/g/files/dvc2011/files/document/2022/02/AEMR Woodlawn Bioreactor %26 Crisps Creek IMF recovering energy from the methane gas in the form of bioenergy, sorting waste and recycling secondary raw material[300]. This eco-precinct is spread over 6,000 ha, and in addition to a bioreactor landfill, a bio-energy plant, and a MBT plant there are other facilities including a wind farm, a solar farm, as well as agriculture, horticulture and aquaculture are also undertaken there[301].

According to the U.S. Environmental Protection Agency, the bioreactor is permitted to accept wastes which are classified under General Solid Waste (Putrescible) according to the Waste Classification Guidelines Part 1: Classifying Waste (EPA,2014). The EPA has provided details of the required licenses, and the management has to maintain timely report of operating, administrative, and reporting conditions of the bioreactor. The performance report and the standards that needs to be adhered to can be found here.

19.2.2. Outer Loop Recycling and Disposal Facility, Louisville, Kentucky

A regional facility situated in Louisville, Kentucky providing convenient and safe disposal services for businesses, communities and industries living in the surrounding areas. The systems that are in place includes the following:

Figure 83: Outer Loop facility

Source:https://www.wmsolutions.com/pdf/factsheet/Outer_Loop_Fact_Sheet.pdf

- **Containment design:** The landfill cells have been constructed using a composite liner system, that provides a barrier to protect groundwater. The liner is a 60-milimeter High Density Polyethylene (HDPE) liner, which is in direct contact with the 2-feet thick clay layer, creating the barrier to protect the groundwater.
- **Leachate collection and treatment:** The leachate is collected onsite and is treated using sequential batch reactor and then is discharged to Publicly Owned Treatment Works (POTW).
- **Groundwater monitoring:** It is monitored through 2 under drains and 5 groundwater wells. These are sampled every year to monitor that they meet the quality parameters, the water levels are checked at all the 54 groundwater-monitoring locations quarterly, to evaluate the hydrology and to ensure that the inward hydraulic gradient is being maintained.
- **Landfill gas management:** LFG is collected and managed through the flare system to prevent odor and reduce emissions. The gas is collected through 233 wells, managed by the flares systems as per the federal requirements.
- **Site security:** The site security is controlled; the facility has limited access and can be accessed through a single gate only. During working hours, the gate is monitored by trained professionals and during non-working hours the gates are locked. The perimeter is secured through fencing, electronic surveillance and natural barrier[302].

Few other case studies that can be referred to are as follows:

Kettleman Hills Facility

Virginia Landfill

Sainte Sophie Shines

Miramar landfill

Sudokwon landfill

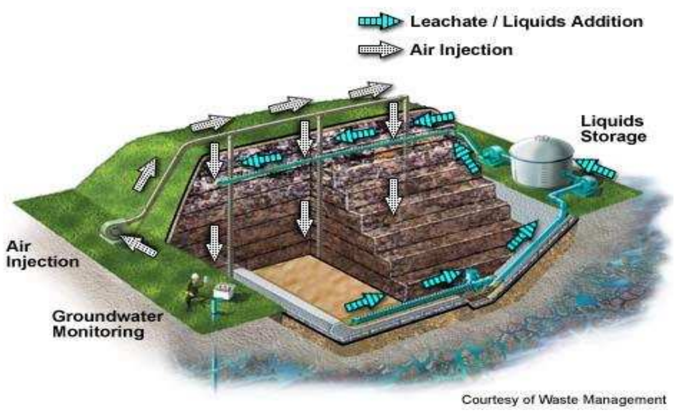
19.3. Working principle of technology

The working principle of the different types of bioreactor landfills as mentioned in the initial part of the chapter are as follows.

Aerobic

Aerobes are organisms that use oxygen for cellular respiration. In this the waste degradation is optimized by improving the aerobes' conditions. Aerobic respiration derives energy from organic molecules consuming oxygen and producing carbon dioxide. In aerobic bioreactors, the waste degradation is optimized by improving the condition for these aerobes. In this process no landfill gas is produced.

Figure 84: Aerobic landfill



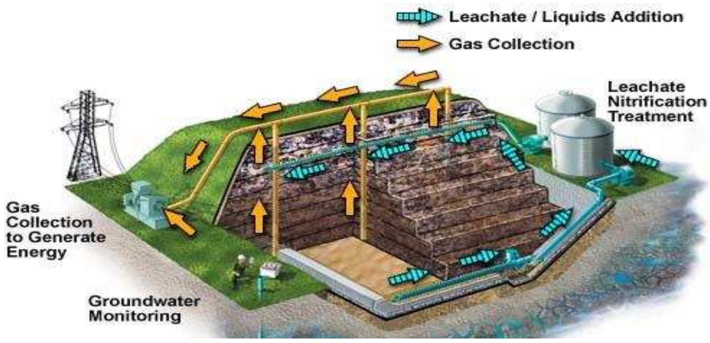
Source : https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf

Since aerobic respiration generates metabolic heat in large quantities, the water requirement is also significantly large. To promote aerobic activity, air or oxygen is injected into the waste mass through vertical or horizontal walls. Liquids are added by recirculating leachates, where the leachate is removed from the bottom, transferred to liquids storage tanks through pipes, and re-circulated in a controlled manner.

Anaerobic

In landfills anaerobic bacteria converts organic waste into organic acid, then into methane and carbon dioxide. The anaerobic bioreactor accelerates the degradation process by improving the condition for the anaerobes. In the landfill the anaerobic conditions develop naturally, no intervention is required to create the condition, but the water percentage in the landfill is typically 10-25 percent. And to optimize the anaerobic degradation conditions to near field capacity the moisture percentage needs to be at 35-45 percent.

Figure 85: Anaerobic landfill



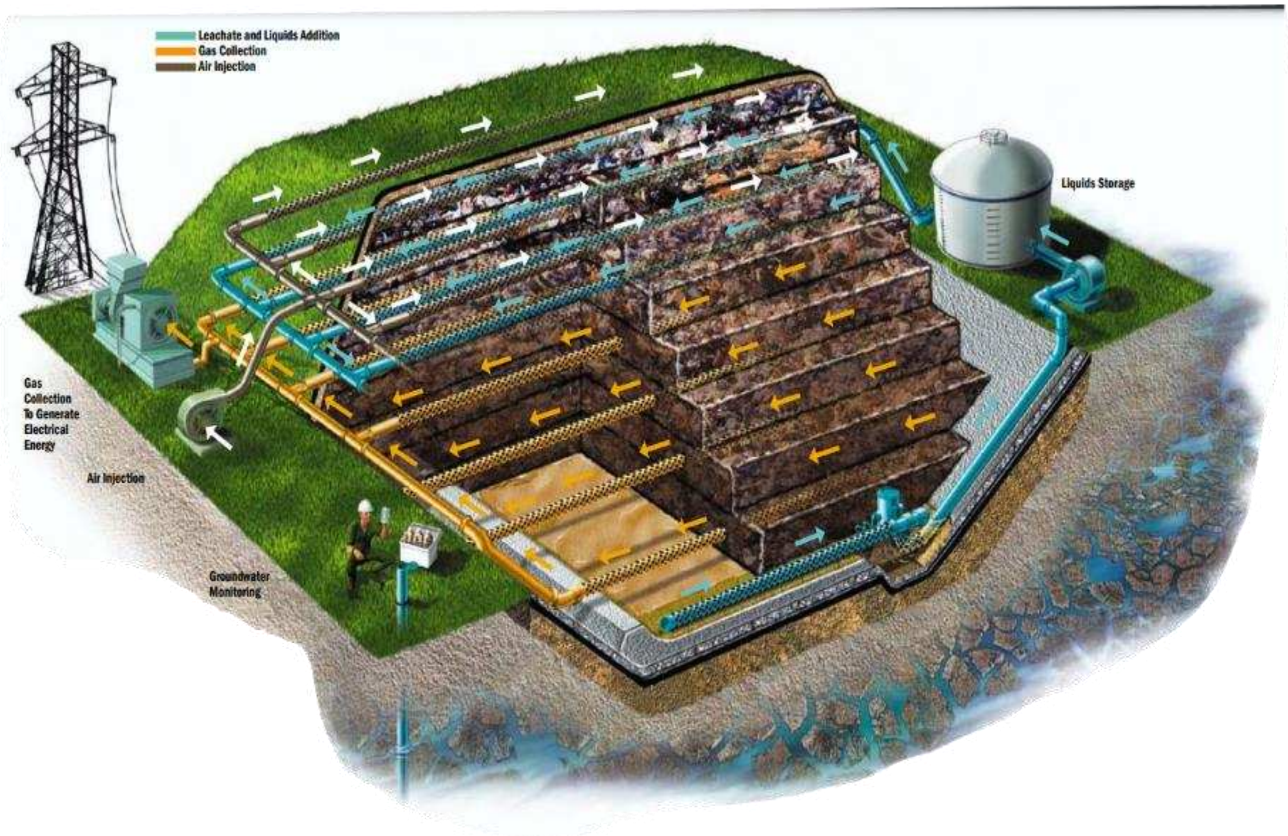
Source : https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf

The moisture is created by adding and recirculating the leachate. And when leachate is not enough to meet the moisture requirements, other sources like storm water, sewage sludge, non-hazardous liquid wastes are added and recirculated in the system. As the moisture contains reaches the optimal level, the waste degradation increases, the amount of landfill gas produced increases and the density of the waste also increases. The duration of the gas produced is short, thus the gas collection system must be able to handle high peak volume but for a short period of time.

Hybrid (aerobic-anaerobic)

In this hybrid system the waste degradation is accelerated by combining the attributes of both aerobic bioreactor and anaerobic bioreactor. This sequential treatment leads to rapid degradation of food and other degradable waste at the aerobic stage, that leads to reduced organic acid production at the anaerobic stage leading to early onset of methanogenesis.

Figure 86: Hybrid landfill



Source: https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf

There are different lifts installed in the system that serve different purposes. In the uppermost lift the waste is aerated, and in the lift just below it, the liquids are circulated. And in the following lift, the landfill gas is extracted and collected. There are horizontal wells installed in each lift that conveys air, liquid and gas in the respective lifts. The advantage of this hybrid system is that it combines the efficient treatments of aerobic system and the simple operations of the anaerobic system as well as destroying any volatile organic compound.

Facultative

In this system, the anaerobic process is combined with a mechanism to control high ammonia concentration that develops when moisture is added in the landfill. In this if leachate contains high level of ammonia, it is treated with nutrification, that converts the ammonia into nitrate. This treated leachate is then circulated in the landfill. Certain microorganisms like facultative bacteria use this nitrate for respiration when oxygen is not present. This process is called denitrification, that produces nitrogen gas, that results in nitrogen being removed from the system effectively.

Figure 87: Facultative landfill

Source: https://www.wm.com/sustainability/pdfs/bioreactorbrochure.pdf

Facultative bioreactor also requires maintaining the adequate moisture level for optimal operation. Like other bioreactors here also leachates, liquid waste, bioliquids, surface water etc. is added to optimize the moisture content[303].

19.4. Conditions determining suitability of technology

There are various requirements that needs to be considered before setting up a bioreactor landfill which are as follows:

- **Site requirements:** For selecting the site various factors needs to be considered like health and safety of people, hauling distance, local geology, zoning, confirms with solid waste management plan and land use plan, safeguard against any contamination, accessible in any weather condition, availability of soil suitable for daily and final cover, ensuring environmentally sensitive areas not affected during operation and beneficial end use after closure.
- **Land requirement:** A large area of land is required to set up a bioreactor landfill. The facility needs to have space for tipping area, place to store daily cover and final cover, area to set up receiving and treating facilities, administrative building, leachate treatment area, processing and utilizing LFG, etc.
- **Liquid requirement:** Bioreactor landfill needs enough water to maintain the optimum moisture requirement to be able operate efficiently. One of the sources of water is storm water, but in areas where there is low precipitation level, in such areas, other options like sewage sludges, non-hazardous wastewater, etc. is added to maintain the moisture level.
- **Managing methane generation:** The methane generated needs to be captured and then should be transported to power generation facilities. Generating power from the captured methane gas, becomes an environment friendly alternative to its carbon emitting counterparts like coal and other fossil fuels[304].

19.5. Potential for symbiosis with other repurposing options

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure needs and requirements of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar.

The detailed analysis for this option has been done in section 25.

19.6. Potential environmental impact locally and GHG emission reduction potential

The bioreactor landfill has various environmental benefits. Some of them are as follow:

- The landfill gases (LFG) are generated in a controlled environment, thus the LFG produced is of improved quality, and it becomes economical to recover and utilize it.
- In the controlled condition, the leachate is contained and recirculated, and in certain cases treated and recirculated and the LFG emissions are also controlled and contained, thus reducing the impact on surface water, ground water and nearby areas.
- The bioreactor improves the chemical and biochemical transformation of both inorganic and organic constituents, resulting in improved leachate that is sent out for final treatment.
- Bioreactor landfill reduces environmental liability and risk, as the chances of leachate effecting subsurface elements is reduced, the solid wastes are settled in a controlled condition and the LFG produced during the process is contained and is carried on for further utilization.
- In this system, the solid wastes are degraded through microbial process, and engineered mining removed inert end product. Thus the end product was a compost like substance, that could be spread on the land, , and the bioreactor cell could again be reused[305].
- Bioreactor landfill reduces greenhouse emission. Firstly, it reuses landfill gases, preventing methane emission. Secondly, methane production acts an alternative for fossil fuels for generating electricity, leading to reduced carbon dioxide emission[306].

19.7. Employment effects

For a proposed sanitary landfill to be set up in Okhla, New Delhi, it was estimated that for constructing the sites skilled, semi-skilled and unskilled locals would be required. In addition to that, during the operations skilled, semi-skilled and unskilled individuals would be required. So, it is expected that the direct employment generation would be 20-25 people and indirect would be about 250 people[307].

19.8. Economic feasibility analysis

For setting up an 8-acre cell, the cost of construction can vary from USD 160,000 for horizontal trenches to USD 640,000 for vertical injection wells. For a 10-acre cell, treating or disposing of leachate ranges from USD 54,750 to 602,250 annually. And the tipping rate is assumed to be USD 40 per ton[308]. A complete feasibility study can be found in the link here.

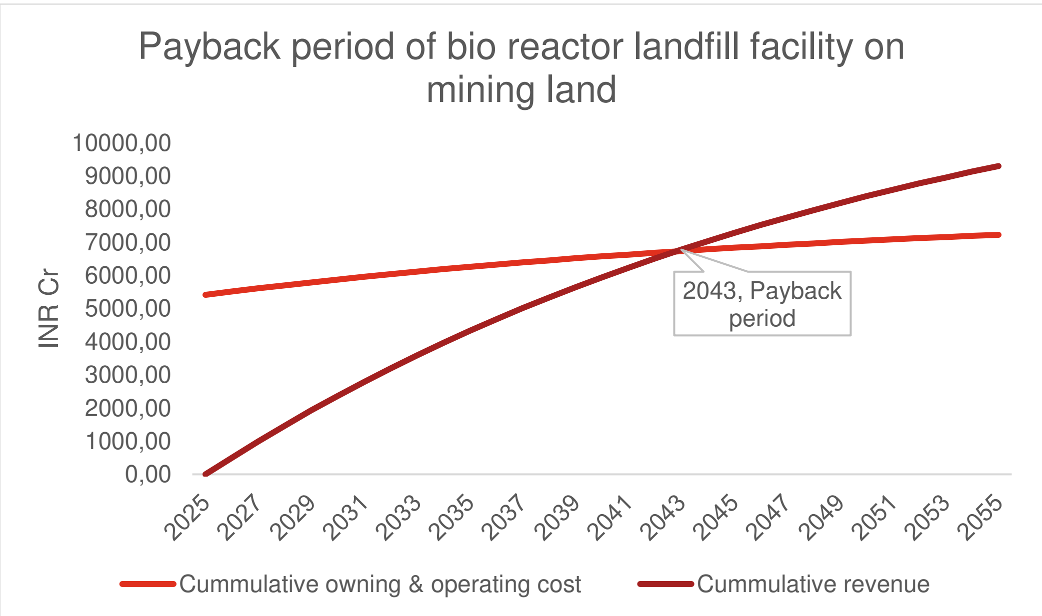
We have prepared an economic model based on the repurposing of a mine site to a waste disposal site for which assumptions taken are tabulated below.

Table 62: Assumptions for economic model of waste disposal – bio reactor landfill at mine site

S.No.	Parameters	Value	Remarks
1	Waste disposal area	100 Ha	
2	Life of project	30 Years	
3	Amount of material dumped in 30 years	42 million tonnes	
4	Capital cost	5685 INR Cr	PwC Analysis
5	Opex	110 INR Cr	PwC Analysis
6	Escalation on Opex	2%	PwC Analysis
7	Electricity produced	6.9 million kwh	PwC Analysis
8	Selling price of electricity	2.99 INR / kwh	PwC Analysis
9	Escalation on selling price	5%	PwC Analysis
10	Price of dumping	4014.62 INR/Tonne	PwC Analysis
11	Escalation on dumping price	2%	PwC Analysis
12	Discount rate	6%	

Source: PwC Analysis

Chart 8: Payback period of bio reactor landfill facility at mine site



Source: PwC Analysis

19.9. Pros and cons

There are various advantages and disadvantages of setting up a bioreactor landfill are as follows.

Table 63: Pros and Cons of bioreactor landfil

Pros	Cons
Waste management: Waste gets settled down rapidly, and the volume reduces and settles down in 5 to 10 years	**Investment costs:** Initial investment cost is high as network of leachate and air pathways needs to be constructed
Environment: The leachate quality is not harmful for the environment	**Skilled labour:** Skilled labor is required to operate the bioreactor efficiently
Reusable land: The land can be reused immediately after closure	**Safety:** Controlling temperature and moisture is of utmost importance
Economic benefit: Large gas is generated in a short span of time, bringing huge economic benefit	
Costs: Leachate is recirculated within the bioreactor reducing the cost of treating and disposing leachate	
Employment and revenue generation: The option generates employment and revenues for the region.	

Source: PwC Analysis

19.10. Suitability for India

As of June 2023, India is the most populous country in the world. And as a result, the waste disposed of daily is also huge. If the abandoned mines repurposed to bioreactor landfills, it would add another waste disposal center. In addition to that since the waste degrades faster than conventional method, the land can be reused again faster leading to increased land utilization.

Considering the conditions determining suitability of bioreactor landfills, the suitability of bioreactor landfills in abandoned Indian mines have been analyzed in detail in Section 26.

20. Water Storage and Flood Protection - As Repurposing option

20.1. Introduction to repurposing option

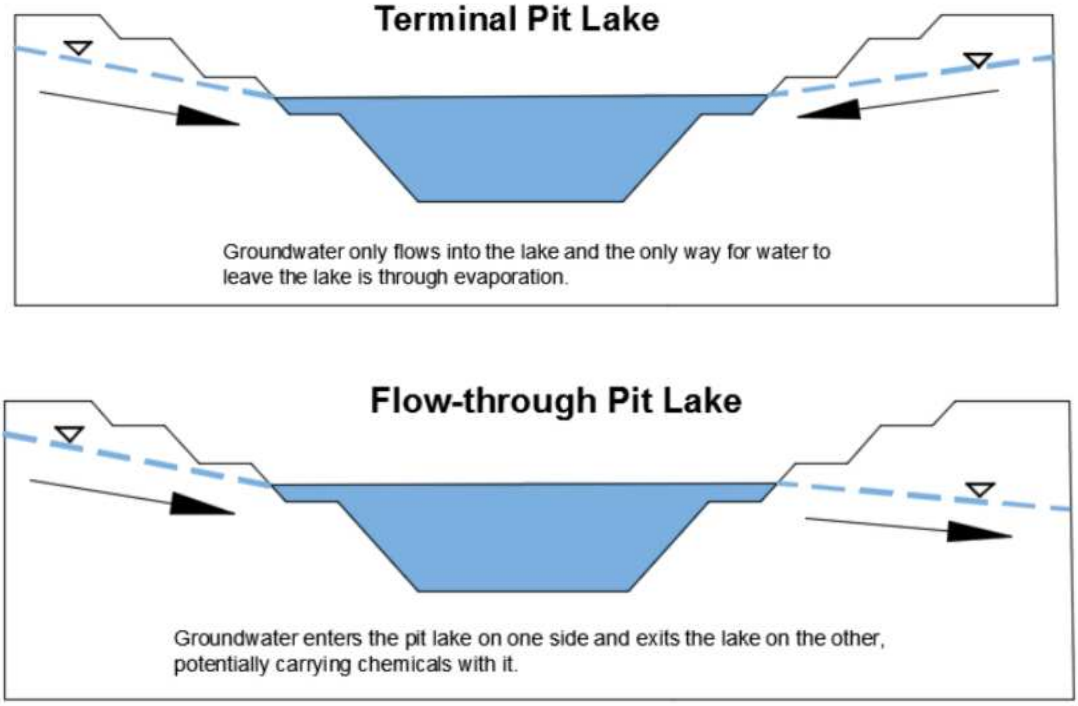
Pit lakes are the result of open pit mining activities. When during the excavation process the mine pit gets deeper than the underground water table, the pits start to get filled with the water, and the mining company, either has to cease their operations, or to continue their work, needs to pump the water out on continuous basis. And once the mining activity is done, the water is no longer pumped out and the mine pit converts into a pit lake.

There are different types of pit lakes:

Terminal pit lakes- It means that there is a low spot, and the ground water keeps flowing and accumulating in the pit, and water can escape only through evaporation.

Flow through pit lakes- In this the water flows in from one area and flows out from another area. Generally, the pit walls are porous and the water seeps and migrates out[309].

Figure 88: Types of pit lakes



Source: https://ndep.nv.gov/uploads/land-mining-faq-docs/Pit_Lakes.pdf

The pit lakes harbor large quantity of water that serves as an alternative water source for the locals and places that face water scarcity. People around the pit lakes use the lake water for their household requirements.

Certain pit lakes in Germany like Stöhna, Zwenkau, Borna and Witznitz are used to mitigate flooding. These form a bypass for flooding rivers, where the lake outflows and river offtake are diverted in a controlled manner, that the flood water gets stored in these pit lakes. And when later on required the water is again released back[310].

20.2. Global best practices with examples

20.2.1. Pit lakes of Raniganj

Figure 89: Pit lake of Raniganj

Source: https://www.indiawaterportal.org/articles/pit-lakes-

There are numerous abandoned open pit mines in West Bengal and Jharkhand, which have become pit lakes and have visiting grounds for various migratory birds. The Raniganj coal field (RCF) has numerous pit lake clusters in the state. The RCF has an area of 1530 square km, of which around 1306 square km was coal bearing land. Mining operations started in RCF from 1774, and led to formation of overburden dump, pit lakes, voids, etc. at the mining site. The pit lake started forming once pumping out the water stopped, and groundwater, surface water, rainfall, etc. helped in further increasing the volume of the lakes. The area of the lake ranges from anywhere between 1-70 hectare of the surface area, with the depth ranging from 10-70 m deep. The age of the pit lakes is between 5-80 years, and the oldest one is nearly 100 years old[311].

20.2.2. Portsmouth Mine Pit Lake

The Portsmouth mine was an iron and magnesium mine, that operated from 1911 to 1978. In 1957, the site also served as the launching site of a big stratospheric balloon, a part of Air Force's Project Manhigh. The lake is one of the deepest lakes in Minnesota with a depth of 137 m (450 ft) and with a surface area of 49 hectare (120 acre)[312]. During the mining operations, water was pumped out from the pit regularly, which was more than 100 m deep at certain places. When the operations ceased, water started to fill the pit, creating lakes where the shoreline composes of glacial sediments. The bed rock the mine working and the mine is no longer visible, this proves the effectiveness of the land reclamation and vegetation methods that has been put in place[313].

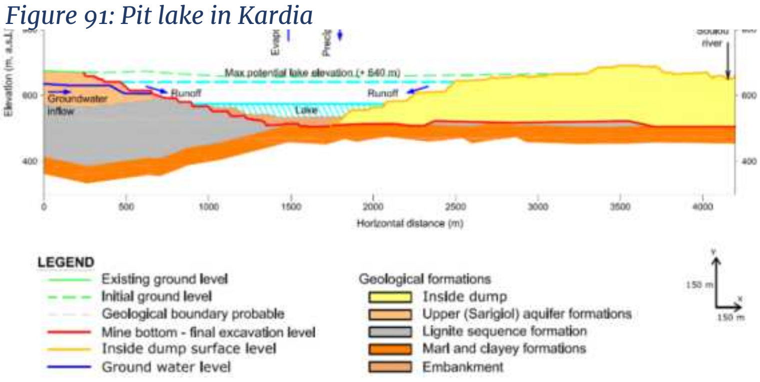
Figure 90: Pit lake at Portsmouth

Source: https://en.wikipedia.org/wiki/Portsmouth_Mine_Pit_Lake

Source: https://roadmarker.geosocmn.org/content/portsmouth-

20.2.3. Kardia pit lake

Figure 91: Pit lake in Kardia



Source: https://www.mdpi.com/2073-4441/14/21/3558

After ceasing mining activities, the mine closure is also an important aspect. And in some mines like a lignite mine in Kardia, Greece, the mine voids were naturally filled with water. The pit lake has various end uses, like it can be used for setting up a pump hydro storage facility, solar photovoltaic panels can be set up, it can also be used for recreational purposes, aquaculture and terrestrial wildlife. Pit lake water has a high concentration of metals and chemicals, after proper treatment of the water, it can be used for agricultural purposes and can also be an alternative source of water for the locals residing in the nearby areas.

Few other cases studies can be referred to as follows:

Northern Minnesota's Abandoned Mine Pit Lakes

Abandon Mine Pit Lake

20.3. Working principle of technology

In situ treatment or direct dosing water treatment is being used to treat mine influence water (MIW). This involves dosing and mixing chemical reagents into the water body for treating it and includes varied treatment that is carried on the MIW. This includes injecting or placing substances like organic carbon substrate and alkaline materials with nutrients directly in the lake to neutralize it and to produce anaerobic conditions that precipitate metals. Injecting carbon sources like molasses or alcohol with nutrients and at times alkaline sources like lime create conditions to precipitate dissolved metals. Adding carbon source promotes exiting bacterial microbes to use sequence oxygen, ferric iron, nitrate, sulfate, and manganese as electron acceptors to grow and form a strong anaerobic (sulfate-reducing) environment.

Alkaline produced as carbon substrate metabolizes, leading to increased buffering capacity of MIW, which leads to increase in pH level of the MIW. The increased pH promotes equilibrium precipitation of dissolved metals like hydroxides and carbonates.

Carbon dioxide is produced and evolves from the mine pool into unsaturated zones, displacing oxygen and reducing pyrite oxidation in lower parts of the mine. Generation of acid rock drainage (ARD) and components of pyrite oxidation are oxygen and ferric iron. To understand the required amount of carbon source to be added, the organic carbon sinks preceding the metal of concern need to be calculated and added along with the metal of concern.

In situ treatment of solid mining waste as residual minerals in tailings, mine walls, or waste rock involves applying amendments like biosolids or phosphate, potassium permanganate, and carbon substrate to stabilize metals in place and minimize formation of leachate[314].

20.4. Conditions determining suitability of technology

The various conditions that are considered for developing pit lakes are as follows.

- Water balance: Calculating the inflow of water of water into the pit and discharge from the pit helps in understanding how much time is required to reach the equilibrium condition. The sources of water inflow are ground water, runoff water, rainfall, pumping water from nearby pits, catchment area and flooded surface water from surrounding river. And the discharge results from evaporation and water seeping out of the lake[315].
- Geomorphology: Studying the evolution and origin of bathymetric and topographic features as a result of the chemical, physical or biological processes taking place at or near the surface.
- Water distribution network: Keeping in place a water distribution system, where the pit water is distributed to the peripheral villages. The water can be supplied in the nearby villages for irrigation purposes through pipelines.
- Treatment plant: Treating the mine water is important, as it may have high metal and chemical content that can damage the nearby land and vegetation. Also, in some cases of a sewage treatment also needs to be place[316].

20.5. Potential for symbiosis with other repurposing options

Table 64: Potential symbiosis with water storage

Repurposing options	Degree to which options can be combined
Pisciculture	Pisciculture can be set up in a pit lake, if the pH level, BOD and COD of the water remains in the acceptable limit. Apart from that with a proper water treatment plant, pisciculture can be set up at ease as the infrastructure requirement is minimal and the returns are high.
Recreational Parks	The pits lakes in the recreational mines not only beautify the area but is also beneficial for the park. The lakes provide additional recreational activities to the visitors, like swimming, boating, fishing, etc.
Ecotourism	Developing pit lakes for ecotourism helps to provide a holistic view of the ecosystem that can thrive in the mines. Providing tours to visitors will help them understand the importance of conserving the nature.
Floating Solar	Certain pit lakes are not suitable for tourism, recreational activities, nature conservation or landscape protection. Setting up a floating solar plant can a suitable option rather than leaving the lake idle and unutilized.
Pumped Storage Hydropower	Pit lakes act as flood protection measures for nearby water bodies. When any other water body near the pit lake overflows, that water gets redirected to the pit lake. Thus, pit lakes can be used as one of the reservoirs for the PSH to generate electricity.
Pumped Underground Storage Hydropower	Pit lakes act as flood protection measures for nearby water bodies. When any other water body near the pit lake overflows, that water gets redirected to the pit lake. Thus, pit lakes can be used as the upper reservoir to generate electricity.

Source: PwC Analysis

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure needs and requirements of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar. The detailed analysis for this repurposing option has been done in section 26.

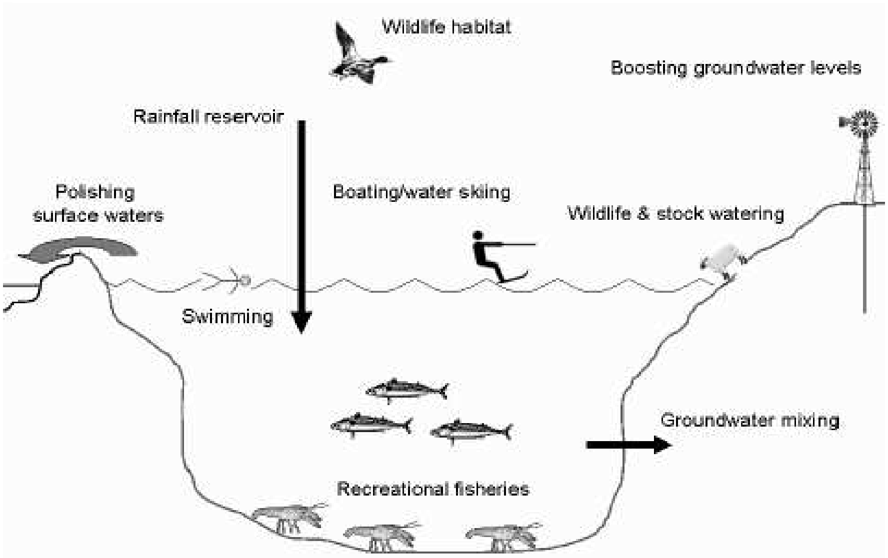
20.6. Potential environmental impact locally and GHG emission reduction potential

Pit lakes are considered to be harmful for the environment, as it is thought that the toxic water might contaminate the nearby areas, and the water might be dangerous for the plants and vegetations. It is considered a liability and measures are taken to pump out the water and to fill up the pit.

But on the contrary, pit lakes can be beneficial for the environment and the community. It not only serves as a water source in water scarce areas, but when multivariate statistical methods, water quality index (WQI) and ecological state macrophyte index (ESMI) were used to assess ecological status of certain pit lakes in Raniganj, the WQI indicated, the water quality in the pit lakes was good and the ESMI indicated that the lakes can be categorized in good ecological status.

In addition to the above water quality parameters including total dissolved solids, pH, Secchi depth nitrate, dissolved oxygen, phosphate, and chloride; and sediment quality parameters including bulk density, organic carbon, pH, particle density, available phosphorus and nitrogen were analyzed on these pit lakes, the result showed required spatial variation is present[317].

Figure 92: Environmental benefits



Source : https://www.researchgate.net/figure/Potential-benefits-of-pit-lakes-to-communities-and-the-environment-In-contrast-to-the_fig1_225472002

20.7. Employment effects

The employment generation of the of pits lakes depends upon its usage. If it is used for recreational purposes, then employment effects of recreational park can be referred. If it is being used for pisciculture, the employment effects of pisciculture can be referred to. And if it being used for domestic and irrigation purposes then few people would be required to set up the infrastructure to transport the water from the lake to the required place where it is being intended to use, and then later on a few people would be required to run the pumps.

20.8. Economic feasibility analysis

The economic feasibility of pits lakes depends upon its usage. If it is used for recreational purposes, then the feasibility study of the recreational park can be referred. If it is decided that the water quality is good enough to carry on pisciculture, the related study can be checked. If the water after being treated can be used for domestic and irrigation purposes, then there will be no revenue model, as providing water for irrigation, or locals using the water body for their daily required does to generate any revenue.

20.9. Pros and cons

The advantages and disadvantages of developing pit lakes in abandoned mine are as follows:

Table 65: Pros and Cons of water storage

Pros	Cons
Numerous options: Pit lakes has numerous end use options like human consumption, nature conservation, aquaculture and fishery, industrial water storage, flood protection, fixing greenhouse carbon, mine water treatment, waterway remediation, disposal of mine and other waste, and research and education.	**Risks:** The main risk pit lake poses include toxicity for terrestrial and aquatic animals, surface water and groundwater contamination, drowning risks, salinization, drawdown, outflow of toxic water contaminating nearby areas, diseases, etc.
Benefits: Pit lakes can provide benefits like health, economic, safety, welfare and aesthetic to the locals and the community	**Risks – landsides:** The steep banks and high walls of pits are vulnerable to falls and landslides. The steep pit walls are only stabilized when the lake is completely filled with water, and that takes a lot of time.
Bio diversity: Pit lakes can e converted into aquatic ecosystems that improves the diversity of post-mining landscapes.	

Source: PwC Analysis

20.10. Suitability for India

Pit lakes formed in abandoned mines, store large amounts of water, supporting the drinking and daily requirements of the local community. These pit lakes formed in the mines of Jharkhand and West Bengal attract numerous migratory birds which arrive there to rest and refuel themselves. The harbor provides alternative source of water at places where there is scarcity of water[318].

Considering the conditions determining suitability of pit lakes, the suitability of pit lakes in abandoned Indian mines have been analyzed in detail in Section 27.

21. Wildlife Habitat - As Repurposing option

21.1. Introduction to repurposing option

There are numerous aspects of abandoned mines. As discussed in the previous section they have cultural and heritage importance, these mines also serve as habitat to endangered and rare species of rodents, bats, amphibians, reptiles, birds and mammals[319]. Humans are destroying the habitats of numerous in the name of development. The species need anthropogenic habitats to survive and thrive. These abandoned mines have features similar to or partially mimic the functions and structures of their natural habitat. The benefits of converting abandoned mines into wildlife are as follows:

- **Anthropogenic habitat:** The abandoned mines become the habitat of numerous animals, like bats, bears, pumas, ringtails, foxes, deer, etc.
- **Biodiversity:** If opencast mines are converted into lakes, or in many instances as years pass water starts to fill up the mines then it becomes suitable to provide a habitat for marine plants and animals to thrive.
- **Employment:** People from the nearby areas are employed to maintain the wildlife and habitats, and to conduct tours for visitors. As they are well-versed with the area, they have a better knowledge and understanding to ensure things and manage effectively and efficiently.

21.2. Global best practices with examples

21.2.1. Mines on Sangre de Cristo mountains

In Colorado, there are numerous abandoned mines situated on the Sangre de Cristo Mountain. Biologist Tim Armstrong was informed that several large carnivorous animals and their remains are found in the mines. He set up cameras on the entrances to find out what species are using these mines. When the footage was checked later on, it was found that numerous species visited the mines like bobcats, bears, lions, ringtails, bighorn sheep, mountain lions etc. The mines were studied over a period of 3 years and 50 mine entrances were monitored and it revealed that 48 vertebrate species inhabited the region, and the smaller horizontal mines was habitat for number of species[320].

Figure 93: Wildlife in mines

Source: https://www.the-scientist.com/slideshows/a-world-of-wildlife-in-abandoned-mines-70054

21.2.2. Abandoned mines to bat haven

Sodalis Nature Preserve, located in Missouri, was formerly a mine situated underneath a hilly landscape near the Mississippi river, is now a hibernation site for Indiana bats which have become rare bats in the area. The City of Hannibal, Iowa Natural Heritage Foundation, Missouri Department of Conservation, U.S. Fish and Wildlife Service and The Conservation Fund protects the 185-acre area. When bats are hibernating, they are vulnerable to disturbance, abandoned mine attracts adventure seekers and they drive vehicles through the passages, light fires and even shoot the bats. So, the consortium has installed bat gates, which allows safe passage for the bats, and prevents people from disturbing them. Also, they have created recreational areas on the outside and have added an adjacent piece of land and that has become an extension of the Bear Creek Trail providing a path to level the terrain for walkers who weren't able to enjoy the hills in the park[321].

Figure 94: Mine being bat haven

Source: https://www.fws.gov/story/abandoned-mine-bat-haven

21.2.3. Abandoned mines create wildlife havens

Figure 95: Wildlife habitat in abandoned mines of Cornwell

Source: https://wilderness-society.org/abandoned-mines-in-cornwall-create-wildlife-havens/

Cornwall was once a hotspot for tin extraction. Thus, there are numerous abandoned mines in the region covering an area of over 3,000 hectares. As the years have passed, nature has reclaimed the area, and has become a thriving ground for a variety of living creatures. These lands have undergone heavy industrial activity, and as a result, have become nutrient less with metal runoff acidic soil. But some unusual plants species that have high metal-tolerance level have colonized in these areas with ease. Like a rare British liverwort Cephaloziella nicholsonii can be found in 11 of such 21 sites. The old quarries and the dry scrubs have flooded over the years, creating a wetland that attracts various wildlife like plants, fishes, amphibians, waterfowl, alligators, etc. These wetlands act as anthropogenic habitat for these species as their original habitats had been drained out for construction and framing purposes.

The unvegetated grounds are also a preferable habitat for insects as well. The temperature in the barren grounds reach over 40°C in summers giving insects an optimal place to bask and hunt. The old shafts and mine buildings are perfect for animals like bats and badgers to settle without any disturbance. The greater horseshoe bat, a species that has become rare in the UK, make underground roosts of the Cornish mining shafts their place for hibernation[322].

Some other stories that can be referred to are as follows:

Little Owls in an Abandoned Mine

Abandoned Mine Filled With Alligators

Abandoned quarries in Wales

Okel Tor Mine

King Edward Mine

Bats and Abandoned Mines

21.3. Conditions determining suitability of technology

To set up wildlife in/on an abandoned mine, there are certain requirements that need to be check listed beforehand.

- **Improving forest cover:** Abandoned mines are generally barren lands, and it might be suitable for certain species, but to bring in biodiversity, plantation and providing a green cover is required. That can be done through soil and moisture conservation, assisted natural regeneration, phytoremediation, etc.

- **Wildlife protection:** There have been many reported instances where poachers and hunters have threatened the wildlife of a region. Proper measures like ensuring forest rangers, animal care takers etc. are there to ensure the safety of the wildlife.
- **Reducing man-animal conflict:** Since humans are capturing the natural habitat of the other species, these alternatives are brought in place as a substitute to their original habitat. It should be ensured that humans don't interfere the wildlife. On the other hand, wildlife also attacks nearby villages. So proper measures should be taken, there is no interference between animals and humans.
- **Noise reductions:** Animals are very sensitive to noise and sounds. And there are numerous plants, machines and equipment installed in the region. Measures should be practiced reducing the noise emitted by this equipment, like using machines and equipment that has built-in silencers and mufflers, ensuring routine maintenance, deploying noise generation machines on rotational basis as well as setting up shock absorbing pads and designated enclosures at isolated places for vibrating equipment and noise generating machineries, respectively
- **Lighting:** Proper lighting should be set up across the area, for both animals and humans to navigate effectively. Availability for proper infrastructure that can provide interrupted and continuous power supply and meet the daily consumption requirement is essential[323].
- **Disposal system** – Waste disposal is another major factor that should be considered for setting up the wildlife. Proper disposal mechanisms are very important for maintaining health and hygiene of the environment, animals and all the inhabitants of the region.

21.4. Potential for symbiosis with other repurposing options

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure need and requirement of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar.

Detailed analysis of symbiosis of wildlife habitat with other repurposing options has been summarized in Section 26.

21.5. Potential environmental impact locally and GHG emission reduction potential

Converting abandoned mines into wildlife habitation region has various environmental and ecological benefits:

- **Afforestation:** Improving infrastructure and carrying on developmental and construction activities has come at the cost of deforestation. And the deforestation rate is increasing rapidly, leading to reduced green covers in cities and nearby areas. To set up a wildlife habitation green cover is required to attract birds and animals.
- **Restoration of habitat:** Habitats are restored to attract the indigenous wildlife back in the region and help them flourish and grow and bring back the ecological balance.

- **Biodiversity:** In Asola Bhatti wildlife sanctuary, there are 193 species of birds, 80 species of butterflies, hundreds of insects and numerous mammals like nilgai, leopards, blackbuck, small Indian civet, Indian crested porcupine, black-naped hare, jungle cat, golden jackal, etc.
- **Water conservation:** Tree and grass are considered the most efficient and cost-effective method to conserve water. The unpaved ground in the parks helps in collecting the rainwater, improving underground water level as well as is an effective mechanism to manage storm water.

21.6. Employment effects

Wildlife tourism also helps in employment generation. As per a wildlife tourism report of Madhya Pradesh, in the state, in the nine tourism villages there are 169 shops that employ 368 people, that is on an average more than two person in each shop. Whereas in the fourteen non-tourism villages there are only 68 shops there are only 94 people employed, that is an average of 1.38 people per shop. In the wildlife lodges 2,525 people were employed on a full-time basis[324].

The government is also creating awareness related to environmental issues among the youth through various schemes and programs. In these schemes and programs, the youth are taught skills essential in forest, environment and wildlife sectors, enabling them to get employed or become self-employed in these sectors. He details can be found in the link.

21.7. Economic feasibility analysis

Back in 2014 the United States Forest Service - State and Private Forestry (USFS) and the National Fish and Wildlife Foundation (NFWF) provided USD 678,000 grant for restoring forests on abandoned mines in Maryland, Kentucky, Virginia, Tennessee, Ohio, and West Virginia. With support from other partners and other in-kind support, a total of USD 1.35 million invested in the forest restoration program[325].

In Alabama, an abandoned coal mine was transformed into a river, that not only added a natural beauty but also became home to rare white lily. As formerly it was a mine, the water had toxic chemicals, heavy metals and sediments was needed to be cleared out, in addition to that the authorities had to deal with other factors like residential and industrial development, failing septic tanks, and agricultural runoff in the river water. The area spread was 5,000 acres, and to clean up the mine’s waste, the state was granted USD 5 million, and the partners, spend additional USD 735,000 to prevent wildfires, reduce woody undergrowth, and help the native plants and longleaf pines[326].

In the year 2000, the Department of Environment, Delhi government commenced a rehabilitation program of the Bhatti mines spread across 2,100 acres. The initial cost to rehabilitate the Asola Bhati Wildlife Sanctuary for 5 years was INR 823 lacs, which extended for another 3 years with an outlay of INR 493.19 lacs. The project got extended by another 3 years[327].

21.8. Pros and cons

There are various advantages and disadvantages of setting up wildlife on abandoned coal mines, some of them are summarized as below.

Table 66: Pros and Cons of wildlife habitat

Pros	Cons
Coming back of rare species: The wildlife habitat that have been set up, provides conditions that will helps the flora and fauna to grow, hence as a result, species that were rare, can now be seen thriving in these habitats.	**Barren land:** These mines are generally barren lands that has no nutrients in the soil, the acid content is very high, as a result, plantation can be difficult.
Ecological balance: Due to deforestation, many birds, animals, insects, etc. were almost extinct and the ecological balance got disturbed severely. But now since the habitats are being restored, they will gradually come back improving the balance.	**Toxic water:** Mines generally get flooded by underground water, or over time water starts to accumulate in the mines. In either way, the water can be toxic and may not sustain wildlife there.
Improved green cover: Restoring habitats will require afforestation and other methods to increase plantation and restoring the land, which will lead to increase in green cover in the region.	**Lack of wildlife crossing zones:** The habitat will be nearby human habitations, that can cause hindrance to both man and animal.
Natures trail and awareness generation The habitats when open to public will provide a nature's trail that will help them to be aware why conserving habitats are important.	
Employment and revenue: Generation of job opportunitites and revenue streams for the region.	

Source: PwC Analysis

21.9. Suitability for India

Generally, converting an abandoned mine into wildlife habitat requires transforming the area before it can be made habitable. Like reforestation, remediation, creating passages so that animals can travel from one place to another without intervening or getting intervened by humans, etc. In certain cases, when the mine is left untouched animals, birds, insects etc. gradually start moving and residing there without any transformation.

Considering the conditions determining suitability of wildlife, the suitability of wildlife in abandoned Indian mines have been analyzed in detail in Section 27.

22. Pisciculture - As Repurposing option

22.1. Introduction to repurposing option

Pisciculture, also known as fish culture, is commercial farming of fish where fish are bred in captive environments in fish tanks and ponds. The process involves breeding, producing, shipping the fish to customers, managing the facility, etc. all the aspects related are managed. In this fish are carefully harvested and cultivated in a natural or stimulated natural environment; applying inorganic fertilizer and organic manure to produce microscopic plant and phytoplankton and as well as feeding and ensuring healthcare of the produce.

<u>There are different types of pisciculture:</u>

Monoculture

In this only a single species of fish is farmed. This has a high production level, and since it is only a single species, thus quality is also good. Generally, the fish which is popular among the customers are farmed in this type.

Polyculture

In this different species of fish are farmed together. It is ensured that appropriate species are farmed together, as certain species don't go well together. Also, the food provided must also be changed from time to time, to ensure all the species survive, as different species have different food required for growth.

<u>There are different methods of pisciculture:</u>

Classic fry farming

In this method, fish eggs are reared to fingerlings after that the grown fishes are discharged into stream water and are fed commercial meal pellets.

Cage system

In this method metal cages containing fish are immersed in the water and the fish are fed artificially. The cage system is very successful and has undergone various technological advancement in installing the cages, but the escaping of fishes and storm-related damage remains a concern cage system.

Pond system

In this method the fish are kept in a tank or a small pond and are fed commercial fish food. Their wase products become fertilizers for the crops. In larger ponds, algae and water plants are developed which become fish food in these cases.

Integrated recycling system

In this method large plastic tanks are kept in greenhouse, containing fish. The water released from these fish tanks is then used to cultivate parsley, basil, and other plants. When tilapia grows in tanks, they consume the algae that naturally grows in the tanks, when the algae are fertilized properly[328].

22.2. Best practices with examples from India

22.2.1. Fish farming in closed CCL mines in Jharkhand

Figure 96: Pisciculture in Jharkhand

Source: https://www.devdiscourse.com/article/headlines/1723445-govt-backing-5-million-project-to-develop-robotic-asparagus-

The abandoned coal mines of Ramgarh, Jharkhand has provided an employment opportunity for educating unemployed youth of the district. They contacted the officials of the fishery department and formed a cooperative society to start fish farming. The department installed a cage system in one of the abandoned coal mines and provided different species of fish free of cost to these people. The fish were fed green grass to increase profitability and to reduce the feeding cost, which or else would have been INR 5,000 per day. As a result, the in-season yield was around 30 tons of fish[329].

22.2.2. Displaced families undertaking cage fish farming in Khelari

The government of Khelari, Ranchi is helping the displaced families by training and encouraging them to take up cage fish farming in the abandoned coal mines. These families were displaced as a result of the Silongoda mine project. They have been trained to do fish farming by the fish cooperatives and government. The district administration provided them with five cages to practice fish farming, additionally, life jackets, boat, fodder, shed house and fish seeds were also provided[330].

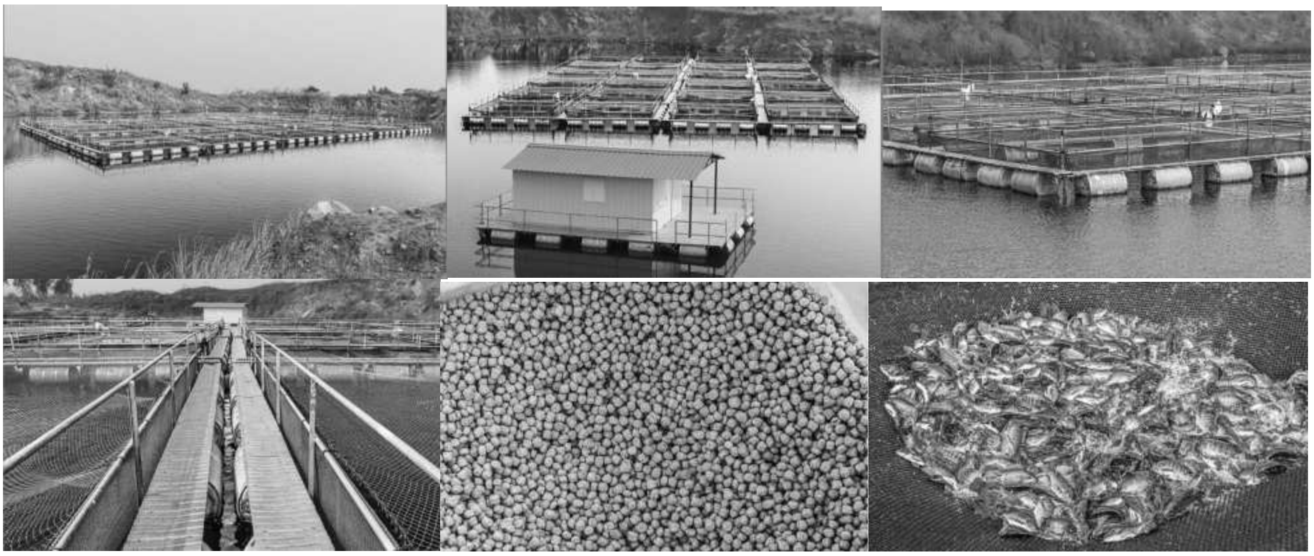
Figure 97: Cage farming in Khelari

Source: https://jharkhandstatenews.com/article/top-stories/4137/displaced-adivasi-leads-cage-fish-farming-in-khelari

22.2.3. Cage fish farming in Nanda village by Self Help Groups (SHGs)

Kaveri Cage Culture Samiti consists of 24 members belonging from the socio-economically weaker sections. The fisheries department provided on-site training and the group registered themselves under the Fisheries Cooperative Act. The abandoned mine in Nanda village remained as a wasteland for several years but it continued to store runoff from large catchments, resulting in a surface water body that is more than 15 meter deep, and the surface area is around 2 hectares. The base of the pit is rocky, resulting in negligible seepage and is easily accessible by road. The infrastructure includes a cage unit and a cage house, and the cage units includes 12 cage batteries. The fishes are raised on supplementary feeding given in right quantity[331].

Figure 98: Cage farming in Nanda village



Source: https://www.millenniumwaterstory.org/Pages/Photostories/Water-and-Livelihood/Fish-Farming-in-Waters-of-Abandoned-Mine.html

22.3. Conditions determining suitability of technology

The various requirements that need to be check listed before planning to set up a fish farming or pisciculture are as follows:

- **Water availability:** Pisciculture requires readily available large water sources, as the stocking up depends mainly on the surface area than on the depth of the water body. The dimensions of the abandoned coal mines should also be able to serve as a storage reservoir as that would ensure that there is enough water available to sustain the pisciculture. Also, water recirculation, aeration, filtration methods and technologies should be implemented in the system[332].
- **Stocking:** The intensity of stocking effects sustainability. Like increase in stocking means increased feed and increased phosphorus, nitrogen and organic matter to maintain the quality of the water. Excessive usage decreases the sustaining ability of the water.
- **Feed and hydro stability:** In polyculture farming, different fishes have different feed requirements, it should be ensured that all the feeds are provided on rotational basis, to ensure all the fishes survive and complete the growth cycle. And also, hydro stability

should be maintained so that after the feed in immersed in it remains stables and the nutrients are not washed away[333].

- **Disposal system** – Waste disposal is another major factor that should be considered for setting up the wildlife. Proper disposal mechanisms are very important for maintaining the health and hygiene of the environment, animals and all the inhabitants of the region.

22.4. Potential for symbiosis with other repurposing options

Table 67: Potential symbiosis with pisciculture

Repurposing options	Degree to which options can be combined
Recreational Parks	Recreational parks have water bodies, and a part of it can be used for pisciculture. That will add a new revenue stream as well as can be used for educational purpose also.
Floating Solar	In Norway, Inseanergy has developed a floating solar technology for aquaculture projects where in it has set up 290 kW floater for salmon-farming and a 160-kW installation for a cod fish farm. The SUB Solar system has been installed on recycled fish-cage float rings and will be used with the onshore power supplies to power fish farms[334].
Water Storage & Flood Protection	Pisciculture can be set up in a pit lake, if the pH level, BOD and COD of the water remains in the acceptable limit. Apart from that with a proper water treatment plant, pisciculture can be set up at ease as the infrastructure requirement is minimal and the returns are high.

Source: PwC Analysis

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure needs and requirements of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar. The detailed analysis for this repurposing option has been done in section 26.

22.5. Potential environmental impact locally and GHG emission reduction potential

The various environmental benefits of setting up pisciculture on abandoned mines can be listed as follows:

- **Habitat protection and restoration:** Farming species of fishes restores the native environment, results in indirect and direct protection and conservation of species and habitats and also restores the quality of the ecosystem[335].
- **Resource efficient:** When compared to other animal protein, farmed seafood is resource efficient. The feed ratio, that is how much feed produces how much protein is less for seafood. For seafood its 1:1 i.e. one pound of feed produces one pound of produce. But for other proteins it is much higher.

- **Controlled variables:** Farmed fishes are closely monitored and are fed processed feeds. Thus, they generally don't have environmental contaminations like heavy metals, mercury, etc.
- **Farming filer feeder:** Fishes like shellfish, eats away the excessive nutrients in the water, and finfish uses fish waste and uneaten feed as food improving the water quality. They offset any environmental impact that would have caused due to installing filter system[336].
- **Lowes GHG emission:** Aquaculture has the lowest GHG emission compared to any other livestock farming. According to a study that was published in Scientific report in 2020, in 2017, aquaculture generated 0.49% of GHG emission by humans[337].

22.6. Employment effects

In an abandoned CCL mine, with the help of the fishery department, (educated) unemployed youths of Jharkhand started fish farming and each of them are earning INR 20,000 to INR 30,000 a month[338]. Deputy commissioner of Ramgarh, has sanctioned INR 3.86 crore to start fish farming in four abandoned CCL mines, which is expected to support cooperative societies and employ around 250 unemployed youth of the nearby villages[339].

The locals believe if pisciculture is practiced in all the 100 abandoned CCL coal mines then around 5,000 people can get employed.

22.7. Economic feasibility analysis

In Jharkhand, two mines spread over 8-10 acres of land, are practicing cage system of pisciculture. A cooperative society of 50 people is carrying out fish farming. In one mine there are 25 cages, and there are two caging seasons. From each cage 2-3 tons of fishes are produced each season, and on an average the revenue is INR 1.5 lac per head per annum[340].

In another district of Jharkhand, Ramgarh, the youth of the district formed a cooperative society to start fish farming on an abandoned CCL mine pit full of water. The fishery department provided different species of small fish free of cost and installed a cage at an estimated cost of INR 3 lacs. The feeding cost of the fish was around INR 5,000 a day, so they found an alternative and started feeding the fish green grass. The youths are now producing around 30 tons of fish in a season earning around INR 15-20 lacs.

We have prepared an economic model based on setting up a pisciculture plant on an abandoned mining site at which water has been accumulated, for which assumptions taken are tabulated below.

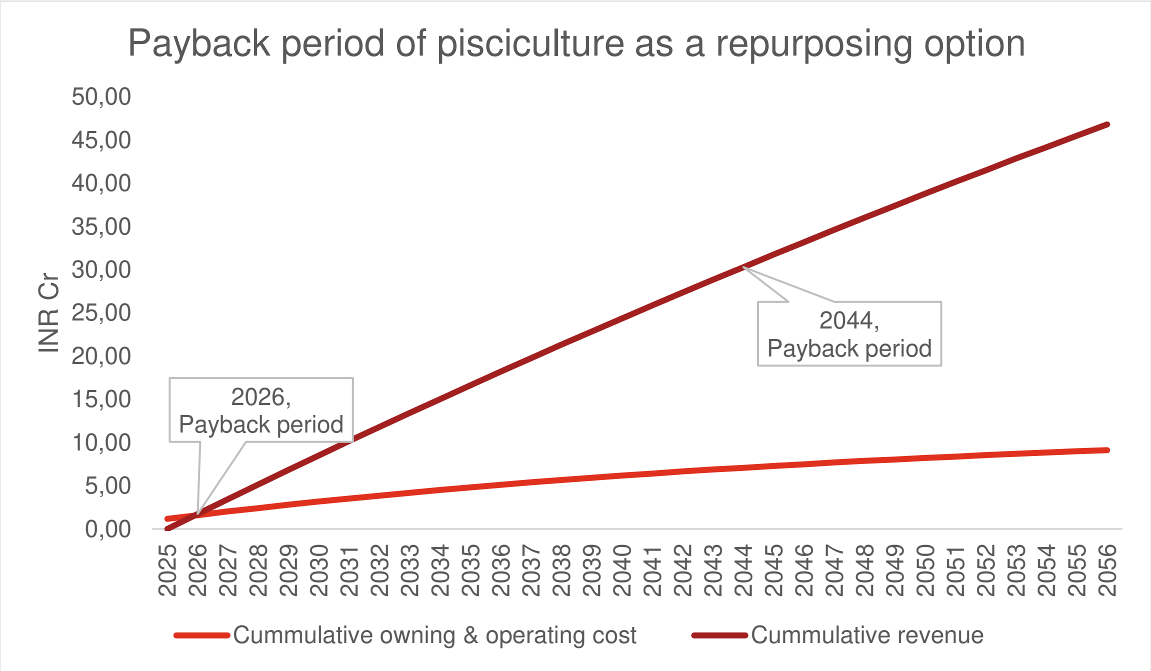
Table 68: Assumptions for economics model of pisciculture on mining land

S.No.	Parameters	Value	Remarks
1	Area for repurposing	10 Ha	
2	Life of project	30 Years	
3	Capital cost	1.11 INR Cr	PwC Analysis
4	Opex	0.47 INR Cr	PwC Analysis
5	Escalation on Opex	2%	PwC Analysis

S.No.	Parameters	Value	Remarks
6	Revenue generation	1.86 INR Cr	
7	Escalation on revenue	5%	
8	Discount Rate	6%	

Source: PwC Analysis

Chart 9: Payback period for pisciculture as a repurposing option on mining land



Source: PwC Analysis

22.8. Pros and cons

The various advantages and disadvantages of pisciculture can be tabulated as follows:

Table 69: Pros and Cons of pisciculture

Pros	Cons
Healthy and nutritious protein Fishes contains Vitamin D and Omega3 fatty acid, which are very crucial for healthy body and is not present in other protein	**Pollution** Fish feed waste, feces, pesticides and chemicals used to control disease contaminates the water and the nearby area
Minimal resource required Not many resources are required to start pisciculture, even a small concrete tank will work	**Spread of disease** If the farmed fishes catch a disease or is affected by a parasite, can rapidly spread among the nearby healthy wild population
Quality of fish The fishes produced in pisciculture are monitored hence they are healthier and of better quality than those of wild fishes	**Overfishing** In order to increase the revenue, people end to over stock, leading to unhealthy, low-quality produce
Maintains ecological balance	

Pros	Cons
Since fishes are produced in confined place, the need to catch wild fish reduces, maintaining the ecological balance	
Employment and land utilization People can convert any unused or infertile land into a pond and start farming fishes providing an additional income for them[341]	

Source: PwC Analysis

22.9. Suitability for India

Any opencast mine that is filled with water and the pH level, BOD and COD are within the acceptable limits can be utilized for pisciculture. The cost of establishing is not very high but the returns are very impressive. Additionally, it provides employment to the nearby locals, thus overall being both feasible and beneficial for the community.

Considering the conditions determining suitability of pisciculture, the suitability of pisciculture in abandoned Indian mines have been analyzed in detail in Section 27.

23. Horticulture - As Repurposing option

23.1. Introduction to repurposing option

Horticulture is a part of agriculture dealing in garden crops like ornamental plants, fruits and vegetables. The scale of horticulture falls in between field agriculture and domestic gardening. It includes cultivation of trees, shrubs, flowers, fruits, vegetables. In horticulture scientific technologies and principles are used to improve the produces by the plants. Thus, as a result, farmers can sell more produce, and more produce will be available for the community. In general intercropping and polycultures are practiced ensuring land sustainability[342].

There are mainly four types of horticulture[343]:

Arboriculture:- Growing and maintaining perennial trees, woody plants, shrubs, vines, etc. is also known as landscape horticulture. It requires the knowledge of art and science to know how these plants thrive and adapt to the environment.

Floriculture:- Nurturing and growing ornamental plants, pot plants, flowers and greeneries. The various plants that can be considered include growing daffodils, roses, chrysanthemum, carnation, tulips, pansies, bluebells, and anthurium.

Olericulture:- Growing herbaceous and edible plants which are mainly used for cooking like includes growing edible roots, stems, leaves, flowers, and fruits like beets, carrots, asparagus, mint, lettuce, cauliflower, tomatoes etc.

Pomology:- Nurturing and growing fruits and nuts that includes the complete process of sowing, harvesting, processing and preserving them. Fruits like mango, grapes, strawberries, pineapples, oranges, nuts like cashew, walnut can be grown in pomology.

23.2. Global best practices with examples

23.2.1. Growing Underground, London (UK)

A company in London that has converted post-war tunnel buried 33 meters down the Clapham High Street into an underground farm. They sow, grow and pack in the facility and send out the produce to a market situated within a mile, and from there it gets distributed across the city. The plants are grown hydroponically, without soil and are watered using tanks that are housed at a lower level. This method requires 70% less water when compared with the water requirement of conventional farming methods. And for the lighting, LED lights are used that are low-cost light and help in the photosynthesis process. The video can be followed for further understanding[344].

Figure 99: Vertical farming in London

Source: https://www.cam.ac.uk/stories/growingunderground

23.2.2. Cycloponics, (France)

A startup in France has transformed and converted the urban underground spaces that remains unused into spaces to produce organic food. In Strasbourg and in Paris, the company is converting former bunkers and abandoned car parking areas respectively into organic farms. The company ensures organic products are produced locally, and a greener city through zero carbon delivery. The underground spaces are optimal for producing micro-sprouts, endives, mushrooms etc.[345]

Figure 100: Underground farming in France

Source: https://cycloponics.co/galerie/

23.2.3. Abandoned coal mine in Texas converted to a garden (USA)

In Freestone County, Texas, a former lignite coal mines ceased mining activities in 2016. A company, Texan by Nature, founded by former first lady Laura Bush, reclaimed the mine land and planted native grass and created wetlands. The mine land is divided into portions, where a certain portion is used for developing seedlings, a portion has been converted into grassland, and in one portion is being used to harvest the produces. The company is using 1 acre of the land to produced 10,000 pounds of yield that has served around 2,000 people per month[346].

Figure 101: Coal mine converted to garden

Source: https://www.texastribune.org/2023/07/14/texas-coal-mine-garden-nrg-restoration/

Some other case studies that can be followed are as follow:

Mining land as farming areas

Biological reclamation of iron ore overburdens

23.3. Conditions determining suitability of technology

For setting up a vertical farm or to start a horticulture in the abandoned coal mines, the various installations and systems that needs to be in place are as follows:

Vertical farming

Lighting: The lighting provided in the underground farming is completely artificial. Powerful lighting is required to grow crops, fluorescent lighting is required to grow vegetables and herbs, and high-pressure sodium (HPS) lights dissipate heat, LED lights are energy-efficient and don't produce heat. Lighting should be selected as per the crop that is being harvested.

Growing medium: There are different growing mediums of plants in vertical farming, namely, hydroponic, aeroponic and aquaponic. Hydroponic, is a soil-free system in which plants are immersed in nutrient-rich solution. In aeroponic, plants are grown in soil, but the water requirement is less, as mist is used for the plant and the soil. And in aquaponic, fishes and plants are combined in a single ecosystem, where fishes are grown in indoor pond, and plant uses the nutrient rich waste produced by the fishes as their food[347].

Efficiency in nutrient and water management: The harvest is done on sacked layer. It must be ensured that the pipe network, dripper discharge and watering rate from the dripper remains uniform at all the levels, and the irrigation water must not contain undesirable pathogens and chemicals, proper fertigation should be practiced. The discharge rate and pressure of fertigation needs to be monitored. Thus, complete circulation, recirculation and drainage of water and nutrients should be managed efficiently.

Electrical conductivity and pH: Higher electrical conductivity leads to increased osmotic pressure and lower EC affects yield and growth. Similarly, pH value ensures availability of nutrients in the plant and requires regulating the presence of sulphuric, nitric, and phosphorus acid in combination or individually. Both EC and pH need to be regulated regularly.

Aeration of roots: In addition to cell growth, roots require oxygen to be able to absorb nutrients and water. Thus, a balance of oxygen and water needs to be maintained and should be standardized or efficient produce[348].

Horticulture

Preparatory land: The land is divided into different parts and is segregated into areas for mother plants, seed production, raising seedlings and storage of seedlings or perennial plants that have been propagated vegetatively.

Required structures: The structures that are required include work shed, polyhouse, fencing and store cum office.

Managing the farm: Seedbed and nursery bed, collecting and planting mother plant, storing dried and cleaned soil as well as compost manure, producing flower seeds, storing propagated plants, manuring, watering, drainage, protecting the pant and finally harvesting them. Followed by packing and handling the harvest, storing them, and marketing and distributing them among the people[349].

23.4. Potential for symbiosis with other repurposing options

Table 70: Potential symbiosis with horticulture

Repurposing options	Degree to which options can be combined
Pumped Storage Hydropower	Horticulture can be set up near the reservoirs, and the water can be utilized for irrigation purposes. And electricity requirement can be fulfilled with power generated by the PSH plant.
Recreational Parks	Horticulture ca be incorporated in a recreational park very efficiently. The produce can be used in the various restaurants present in the park. Additionally,

Repurposing options	Degree to which options can be combined
	it can also become a tourist attraction spot, where the visitors also indulge themselves to learn and understand the concept of horticulture.
Wind Energy on Mining Land	Be it undertaking horticulture in open cast mine, or vertical farming in underground mine, both the set up have some sort of power requirement. Wind turbines will be able to meet the requirement and the excess can be synced with the grid. This will make the farm self-reliant for its power requirement.
Thermal Energy storage	Land required for horticulture is subjective to availability, so can be set up with ease. And thermal energy is quite beneficial for horticulture as mentioned below: • Generated heat is available round the clock • Makes systems run more efficiently • Makes heat generators smaller • Allows multiple heat generators to coordinate effectively • Provide heating backup

Source: PwC Analysis

The symbiosis is at par with all the repurposing options available under the head Eco-Tourism, and Wildlife, namely, recreational parks, eco-tourism, museum, wildlife, horticulture, etc. as these various options can coexist with each other. There can be a recreational park situated in an ecotourist spot, or in a wildlife sanctuary. The infrastructure need and requirement of the options are quite different, but certain parameters like environmental benefit by the options, stay quite similar. The detailed analysis for this repurposing option has been done in section 26.

23.5. Potential environmental impact locally and GHG emission reduction potential

There are various environmental benefits of practicing vertical farming and horticulture on the abandoned mines can be listed as follow:

- **Water consumption:** As mentioned earlier, vertical farming uses much less water as compared to conventional farming. In vertical farming the temperature is controlled by a smart system decreases the water loss, hence water consumption reduces significantly.
- **Crop diversification:** Since vegetation is grown on stacked layers, different crops can be cultivated at a time increasing the yield. And with effective watering systems and feeding techniques the quality and quantity of yield can also be improved.
- **Space saving:** The farming is done underground, no land utilization is required, also since vegetation are grown on stacked layers, the yield from a single place will be much greater than conventional farming.
- **Controlled environment:** In conventional farming, the weather condition and other external conditions are not in control of an individual, thus can adversely affect the produce. But in vertical farming, the complete environment including temperature, lighting, feed, watering, etc. is under control, hence the chance of good yield is much higher[350].
- **Ecological restoration:** Horticulture helps in moderating the urban temperatures, increases the green spaces ensuring sustainability thus benefiting the urban environment through ecological restoration.

- **Reduced GHG emission:** Greenhouse gases emitted in vertical farming less when compared to conventional farming. As land usage is minimal, innovative production techniques are in place, and supports reduced distribution time, thus the system has a whole emits less carbon emissions.

23.6. Employment effects

For a 3,000-bed vertical farm operated in an 80,000 square feet area, around 86 people are involved in running the business. This includes managers, vice presidents, laborer, maintenance staff, drivers, operators etc. drawing on an averages USD 301,791 salary per month[351]. On a 1000-meter square farm, on an average 1,220 man work hour are required per month[352].

As per a 'Benchmark Survey of Horticulture Crops in Uttar Pradesh Area and Production Estimation' published 2020, in horticulture, the employment generated from one hectare of fruit produce is 860 man-days p.a. for cereal it is 143 may-days p.a. And for cultural intensive crops and industrial attribute crops like pineapple, banana, grapes, it is 1,000 to 2,500 man-days p.a.[353]

23.7. Economic feasibility analysis

The economic feasibility for setting up both vertical farming and horticulture is quite different. For vertical farming, a small-scale farm can be set up in around INR 10-15 lakhs, but it can also go up to INR 50 lacs to INR 1 crore per acre. The operational cost will include maintenance, water, electricity and labor. And this cost can be on the higher side as the manpower needs to be skilled and since a complex system needs to be maintained, the maintenance cost will also be high. It can go anywhere between INR 5 - 10 lac[354] per acre. And the yield depends on the crop selected, technology used and environment provided. The revenue depends on the competition available and the demand for the goods. Generally exotic fruits and vegetables are sold at higher prices[355]. An example of the revenue model can be found here.

For horticulture, it can be seen that the production cost of organic produce is around INR 5 million, whereas for conventional produce it is around INR 7.2 million. And the gross income of the organic produce stands at INR 20.4 million and for that of conventional produce it is INR 19.6 million[356].

23.8. Pros and cons

The advantages and disadvantages of both vertical farming and horticulture are as follows:

Table 71: Pros and Cons of horticulture

Pros	Cons
Improved yield Uses scientific technologies and principles to improve the produce. Intercropping and polyculture mutually benefits all the plants, improving the yield.	**High initial investment** Both vertical farming and horticulture require a high initial investment just for setting them up. The equipment, systems, supplies, etc. are quite costly
Increased production	**Energy consumption**

Pros	Cons
As mentioned, vertical farming is done in controlled environment hence with efficient management, the yield can be increased.	Vertical farming uses a lot of energy to operate the environment and lighting to sustain the production.
Improved quality Again, since the environment is controlled and external disturbances does not affect vertical farming, the quality of the produce are of very god quality.	**Regulatory challenges** Since the concept is new, getting regulatory approval is a tedious task. Getting permits, maintaining food safety regulations, etc. are some the challenges that needs to be faced.
Space usage In vertical farming, land usage is very minimal, and the farming is done on stacked layer, space is utilized efficiently.	**Crop failure** Like any other farming, the risk of crop failure is also there. If the irrigation system fails, the equipment breaks down, there is an outbreak of disease, etc. such situation can lead to huge loss.
Reduced water usage and carbon footprint Vertical farming consumes far less and also the greenhouse gas emission is also lower water than conventional farming.[357]	
Employment and local reveneues: Job creation and revenue streams	

Source: PwC Analysis

23.9. Suitability for India

In India there is open cast mines, underground mines and areas where there is both mixed mines. Since horticulture can be done in both types of mines, with proper infrastructure and technologies in place, as well as regulated policies and incentives horticulture can be set up in the mines.

Considering the conditions determining suitability of horticulture, the suitability of horticulture in abandoned Indian mines have been analyzed in detail in Section 27.

24. Additional Repurposing Options

24.1. Data Storage

Iron Mountain

In New York, once an iron-ore mine was previously used for mushroom farming by Herman Knaust in 1936. During the Cold War, he converted his mushroom farm into a secure underground vault, and named it Iron Mountain. The space was being offered to the corporates to protect their information from nuclear attacks and natural disasters. And gradually as the demand increased an old limestone mine was also used to expand the facility.

Until 1978 it provided only underground storage facilities, but afterwards it started providing its services on above the ground facilities as well. The company also provides a digital and cloud storage facility at Boyers that has huge banks of servers. Another advantage of these mines is that there are huge lakes of cold water under the mines, that helps in cooling the heat generating equipment without any extra cost of installing expensive systems. The mine water is circulated through the air conditioning systems and is returned in the lake[358].

Basic requirements to develop data storage systems are availability of nonstop power supply and strong and secure internet service. As mentioned in the previous paragraph, for cooling the systems, water requirement is also a factor to be considered but if water is available below the mines, then it helps in reducing the cost required to set up the storage system.

24.2. Leisure facility

InterContinental Shanghai Wonderland hotel

It is a 5-star hotel, that has been built on an abandoned quarry. The hotel is 18 stories building, the top two layers are at the ground level, the rest 16 stories are descends vertically in the depth of the quarry where the bottom two floors are submerged in an artificial lake. After the building was completed, the bottom of the quarry was filled with water to create an artificial lake. Visitors can dine in underwater restaurants, can enjoy themselves in the underwater swimming pool, or can stay in the underwater rooms and enjoy the view of their sub-terrain surroundings.

The lake provides a range of water sports to the visitors and has a water fall cascading down the quarry, present at the opposite of the hotel, enhancing the overall experience of the people who stay there[359].

Comfort Inn in Coober Pedy

In South Australia previously an opal mine has now been converted to a hotel. Mining activities were carried out in these underground mines from 1918 to 1960. And later after that it was converted to a hotel from 1990 to 2001[360].

Mines Resort City

In Malaysia, Hon Fatt Mines was one of the biggest tin mines in the world. Once mining operations ceased the pit and the crater were left abandoned. The crater was filled with water, and Mines Resort City was developed. The complex has a 5-star hotel, a custom beach and a huge golf course[361].

24.3. Infrastructure

Golf courses

A gypsum mine in Michigan, a copper mine in Montana, a phosphate mine in Florida, and numerous other mines in the US have been turned into golf courses with design and infrastructure that makes them a golfer's heaven.

Zip World

Zip World operates three sites in North Wales and one in South Wales. In the South Wales in the Rhigos mountain range, near Aberdare, it has set up Zip World Tower at the former Tower Colliery a coal mining site. Whereas in North Wales, there are three adventure-tourism spots namely Llechwedd Slate Caverns, Penrhyn Quarry, and Zip World Fforest.

- The Penrhyn Quarry has Europe's longest and world's fastest zip line. There are 4 parallel zip lines that span across 1 mile and is 500 feet over the quarry lake, with a speed of 100 miles/hour.
- The Llechwedd Adventures was previously a slate mine, that offers Deep Mine Tour in the Cavern, has an underground trampoline park, largest underground zip wire line course in the world, Europe's first four-person zip line, and world first underground golf course.
- The Fforest has Europe's largest net walkway that is 60 feet above the ground, a hanging zip-line and obstacle course 60 feet above ground, Europe's highest giant swing, and a 1km Fforest Coaster through woodlands.

Sanford Underground Research Facility (SURF)

The Sanford Underground Research Facility (SURF) is home to cutting-edge physics experiments designed to enhance the comprehension of the universe. Situated at the former Homestake Gold Mine in Lead, South Dakota, SURF offers exceptional depth and rock stability, creating an environment ideally suited for experiments seeking to escape the constant interference of cosmic radiation. This interference can impede the detection of rare physics events. In addition to physics experiments, SURF accommodates research in biology, geology, and engineering. Homestake, the mine's previous iteration, held the distinction of being North America's largest and deepest gold mine until its closure in 2002. Over its 126-year lifespan, it yielded approximately 41 million ounces of gold[362].

Limestone Mine Bike Park

Louisville, Kentucky is home to the world's only underground bike park. Louisville Mega Cavern is located 100 meters below the ground in a former limestone mine. It offers 320,000 sq ft of trails to mountain bikers, that has singletrack and jumps made of BMX track dirt[363].

Previously the mine served several different purposes. In the early 1990s, the underground mine's nearly one million sq ft area was used as a dumping site for dirt and rock, and then later was used as a storage site for businesses. Further later zip lines were installed in a section of the mine and in recent years drive-thru was set up to show underground Christmas light that drew long lines of cars during the holidays. Two decades of dumping gradually built the floor and there were request from visitors and bikers to set up a bike park, and the bike park opened for business in February 2022[364].

Dalhalla Concert Venue

Located in a former limestone quarry in Sweden, Dalhalla is an open-air amphitheater used as a summer music venue. The quarry is 60 m deep, 400 m long and 175 m wide, was in operation till 1990, and was transformed as an amphitheater and opened to the public in 1995. With seating capacity of 4000, the location and landscape are protected from noise pollution, and its acoustical qualities of the place can be compared with few of the best outdoor stages in Europe[365].

Old silver mine structure in Ontario

Located in Cobalt Mining District, during the period of 1904 to 1924, more than 32.5 million ounces of silver was extracted from the mine. The structure sits above the mine and after mining stopped, it has been repurposed several times. First as a grocery store, where the shaft was used as refrigerator, a wig store, a Firefighter's Museum, a mining developed officer and now finally is being used as office of White Mountain Publications.

The 350 feet mine shaft at the bookstore's filled in to prevent anyone from falling down by accident and to make the place warmer so that no wind is blown up from the underground[366].

From granite quarry to soccer stadium

Sporting Clube de Braga stadium, has a seating capacity of over 30,000, is an example on how construction and architecture can be amalgamated with the surroundings and integrated into the nature and how to unite the past with the present to bring new life to forgotten areas. The stadium, also known as Municipal Stadium of Braga is designed on an old granite quarry, with two stands facing one another. One sits on the hill the other on 16 concrete blocks, with dozens of steel cables hanging between them.

There are no stands behind the goals, there is a granite wall on one side other, unobstructed views on the other side creating a continuity between the nature, stadium, and the rest of the city. The shape of the stadium harnesses sunlight and leads water away from the field that is rerouted[367].

Government office

The US Office of Personnel Management Retirement Operations Center is located inside a mountain which once used to be a cavern of limestone mine. Located in Boyers, Pennsylvania, since 1954 the massive subterranean facility has been used as storage facilities after the mining operations ceased. The former mine now employs countless local employees who process endless amounts of paperwork related to the retirement benefits of Federal employees.

Number of similar underground storage fortresses were created and leased during the Cold War as these underground climates formed a natural protection against bombardment and EMP attacks making them ideal to store delicate files and operations[368].

Repurposing Mine Sites for Agricultural Opportunities

Business for Development, an NGO, is focused on using market-focused agricultural opportunities to create sustainable livelihood. They have been working with Umsimbithi Mining Ltd, Glencore Coal South Africa, Impact Catalyst, the International Council on Mining and Metals (ICMM), and the Mine Water Coordinating Body (MWCB) to pilot variety of winter wheat at community land in Mpumalanga and on rehabilitated mine site.

It is expected that there will be approximately 2.0-2.5 tons per acre for the irrigated pilot sites and 1.5 tons per acre for the dryland pilot sites. When the crop reaches 30% moisture levels, the NGO will take and compare the following from samples drawn from four control sites:

- Virgin land irrigated with fresh water
- Virgin land irrigated with treated mine water
- Remediated land irrigated with fresh water
- Remediated land irrigated with treated mine water

Tests will be conducted to review if the remediated land and treated mine water leaves the grain with chemical or mineral residues[369].

24.4. Oil reserve

Strategic Petroleum Reserve (SPR)

SPR is the largest supplier of emergency crude oil, where the oil stocks are federally owned and stored in huge underground salt caverns. The authorized storage capacity is of 714 million barrels and the sheer size of the SPR makes a significant deterrent for oil import cutoffs and plays a key tool in foreign policy.

SPR was primarily established for reducing the impact of disruptions in petroleum products supplies and to carry out obligations of the United States under the international energy program[370].

Oil reserves in underground rock caverns

Since 2008 India began storing strategic oil reserves in underground rock caverns. It can hold 10 days of India's requirements. India stores 5.33 million tones, about 38 million barrels. of crude oil in underground rock caverns which were built and filled in the past decade only at three locations on the east and west coast. In July 2022, the government had given a green signal to build two new reserves, with the help of private investors, in rock caverns, to raise the total capacity from 9.5 to 22 days overall days in the three existing caverns[371].

24.5. Disposing off nuclear waste

Disposal of radioactive waste in abandoned mines

Countries that use nuclear energy are in the favor of disposing of Low-Level and Intermediate-Level radioactive waste in mined repositories that has series of tunnels or drifts connected to disposal tunnels at a few hundred meters depth. Abandoned mines can serve as repositories for High-Level Waste in the form of spent reactor fuel. The technique involves encapsulating waste in metal canisters surrounded by densely compacted smectite clay in relatively shallow mined repositories and in very deep bored holes. Intermediate-Level radioactive waste can be disposed of in caverns in the form of packages of metal containers cast in low-pH concrete and embedded in dense smectitic clay[372].

Planned used of disused iron mine for nuclear waste

Its planned that Konrad's tunnels will become home to more than 300,000 cubic of radioactive waste from Germany's nuclear power stations. Konrad mine in Salzgitter, Germany, produced iron for from 1867 to 1976. And now around half of the nuclear waste that Germany has ever produced is being planned to be buried in the mine. Buried deep underground, the material will be left to slowly decay.

Some of the radioactive elements take decades to decay. But others like plutonium-239, neptunium-237 and iodine-219 can linger on for around thousands of years. Thus, burying them deep underground in secure containers is probably the best option[373].

25. Repurposing Matrix for Indian Coal Mines

There are various parameters that need to be assessed before determining the preliminary suitability of a repurposing option which can be deployed at a mine site. These factors include:

- Type of mining – Open cast or underground
- Land requirement – The amount of land that will be required for repurposing the mining land.
- Location – Refers to the geographical location of the mine and the meteorological factors of the area.
- Accessibility to the mine site – The ease of reaching the mines site. This factor encompasses nearest railway station, road network nearby, nearest airport and bus stand.
- Power transmission infrastructure – Is the availability of the required infrastructure to transmit electricity from the point of generation to distribution and consumption points. Transmission infrastructure includes transmission lines, substations, transformers, switching stations, control and monitoring system.
- Geotechnical parameters – Influences the stability of slopes in open cast mines and the durability of underground excavation. An assessment of the site of installation is required before going forward with any repurposing option.
- Presence of water – In the case of PSH, PUSH, Pisciculture presence of water is of high importance as it acts as a source of electricity.
- Presence of reservoir to store/trap the energy source – In the case of energy storage options the presence of a storage reservoir is of utmost importance. The reservoir may need to be modified as per the needs of the energy storage system.
- Natural water source nearby – It will be required to fulfill the water needs of the system in case the net availability of water is not as per the requirement.
- Head difference – Is the level difference between upper and lower reservoir in PSH and PUSH. The head difference is an important parameter used for assessing the applicability of PUSH and PSH plant.
- Net water availability – Is the net amount of water that is present in a mine and is calculated by subtracting water outflow from water inflow in a mine. The water gets accumulated in a mine due to ground water inflow, rainfall and runoff water, streams and river, and outflows due to seepage, geological features like fault and fractures.
- Solar irradiance – It Refers to the power generated by the solar radiations per unit area and its unit is W/m^2. This is an important factor for establishing a solar power plant.
- Average wind speed – Refers to the average speed of wind in an area in a day. It is measured in m/sec. This is an important factor that has to be assessed while establishing a wind power plant.
- Depth of mine shaft – Is applicable to underground mines. This factor influences a possible PUSH and gravity storage option.

- Ventilation in underground mines – This factor is of importance to underground mines as maintaining adequate ventilation in the working areas is necessary for the people working on the infrastructure in the underground mines.
- PH of water – The PH of water will have an impact on the machines that might get corroded due to the acidic nature of the water.

25.1. Repurposing matrix

A repurposing matrix has been prepared that covers the preliminary conditions that have to be assessed before going forward with any repurposing option.

Table 72: Repurposing Matrix

S.No.	Repurposing Options	Factors Effecting Suitability								
1	**Pumped Storage Hydropower**	Applicable to open cast mine only	Minimum two water reservoir are required with a head difference of minimum 100 m	Assessment of capacity of reservoir which is determined by power output (MW) and energy storage duration	100m to 300m head difference is preferrable	Duration of electricity storage should be generally greater than 6 hrs.	Presence of power transmission infrastructure which includes generators, turbines, transformers, switchyard, transmission lines, substation, grid connection, control system and communication infrastructure	Characteristics of water reservoir: inflow and outflow rates, area, PH of water ranging from neutral to alkaline is preferred.	Impact of rock slope failures and its impact on the lower reservoir	Availability of mine pumps and if it can be utilized for PSH project
2	**Pumped Underground Storage Hydropower**	Applicable to underground mine only	Minimum two water reservoir are required with a head difference of minimum 100 m	Capacity of reservoirs is determined by power output (MW) and energy storage duration	100m to 300m head difference is generally preferred	Duration of electricity storage should be generally greater than 4 hrs.	Presence of power transmission infrastructure which includes generators, turbines, transformers, switchyard, transmission lines, substation, grid connection, control system and communication infrastructure	Characteristics of water reservoirs: inflow and outflow rates, area, PH of water ranging from neutral to alkaline is preferred.	Factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important	Availability of mine pumps and if it can be utilized for PUSH project
3	**Compressed Air Storage**	Applicable to underground mine only	Availability of impervious underground storage for compressed air. This may be done by using plugs and liners in drifts and shaft containing hard rock	Compressed air is stored at 8-10 mega pascal pressure and the storage reservoir should be isolated with liners, plugs or stoppings designed to withstand high pressures in storage facility	The coal should not be present in the storage space	The area for storage has to be dry and should not have water in it	Factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important	Presence of power transmission infrastructure which includes generators, turbines, transformers, switchyard, transmission lines, substation, grid connection, control system and communication infrastructure		
4	**Hydrogen Storage**	Applicable to underground mine only	Availability of airtight underground storage as hydrogen is a flammable gas	Capacity of UG storage depends on the amount of hydrogen to be utilized	Presence of power transmission infrastructure which includes generators, turbines, transformers, switchyard, transmission lines, substation, grid connection, control system and	factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important				

S.No.	Repurposing Options	Factors Effecting Suitability								
					communication infrastructure					
5	**Thermal Energy storage**	Applicable to both open cast mine and underground mine	Solar Irradiance of above 5.2 Kwh/m2 / day is desirable	Land requirement is about 5-10 acres/MW of capacity	water requirement is about 750-920 gal/MWh	For aquifer energy storage a mine should be 20-200 meter deep	factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important	Presence of power transmission infrastructure which includes generators, turbines, transformers, switchyard, transmission lines, substation, grid connection, control system and communication infrastructure		
6	**Gravity Storage**	Applicable to both open cast mine and underground mine	Depth of mine shaft should be atleast 500m in case of underground mine	Presence of power transmission infrastructure which includes generators, turbines, transformers, switchyard, transmission lines, substation, grid connection, control system and communication infrastructure	Availability of weights or heavy material to be transported down the shaft nearby the mine area and the cost of procurement of the material if not present nearby	factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important. The geological stability and integrity of the structure should also be surveyed on time.				
7	**CO2 Storage**	Applicable to underground mine only	Availability of underground storage with adequate trapping mechanism	the CO_2 should be trapped atleast 500m below from the pit top	The underground mine must have suitable geological formations, that can securely and effectively trap CO_2. This involves assessing the presence of faults, fractures, or other potential pathways that could compromise the containment of CO_2.	factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important	The amount of the influx of water into the mine should preferably be low. The mine has to be kept dry by pumping out water for storage of CO_2 to prevent gas pressures which may cause leakage of the gas.	The reservoir pressure should be 30% more than hydrostatic pressure to prevent water influx	The feasibility of CO_2 storage is influenced by transportation cost. The closer the CO_2 capture site to the storage site the better it is.	
8	**Wind Energy on Mining Land**	Applicable to open cast mine only	Average wind speed (m/sec) > 4 m/sec	Availability of land: 0.5 Ha/MW of land	Presence of power transmission infrastructure includes generators, transformer, switch yard, transmission lines, substations, switchyard, grid connection, distribution infrastructure, grid connection, collection system, control system	Preferred location would be on a hill or in an open area without any adjacent obstacles. The tops of smooth, rounded hills, broad plains, and wind-driven mountain gaps are all desirable locations.	The site should be preferably at a little distant from locality due to noise pollution.	Site accessibility- the access roads and tracks to the site must be strong enough to carry big loads without having any weak bridges, overly sharp turns, or high incline.		

S.No.	Repurposing Options	Factors Effecting Suitability								
					and communication infrastructure					
9	**PV on Mining Land**	Applicable to open cast mine only	Average Solar Irradiance (Kwh/m2) is generally preferred to be between 4 to 6 Kwh/m2/day	0.6 Ha of land/MW is required	The land should be wide and open with no wetlands and minimal incline.	The region should receive plenty of sunlight for maximum number of days throughout the year to make the project feasible	Presence of power transmission infrastructure includes inverters, combiner boxes, transformer, switch gear, transmission lines, substations, switchyard, grid connection, infrastructure, grid connection, control system and communication infrastructure			
10	**Floating Solar**	Applicable to open cast mine only	Solar Irradiance (Kwh/m2) is generally preferred to be between 4 to 6 Kwh/m2/day	0.7 Ha of area/MW	The water should be still and should receive sunlight for maximum amount of time during the day.	The area should be wide and open, without restrictions in nearby area.	Presence of power transmission infrastructure includes inverters, combiner boxes, transformer, switch gear, transmission lines, substations, switchyard, grid connection, infrastructure, grid connection, anchor system control system and communication infrastructure	The mine should be such that it remains flooded with water throughout the year		
11	**Geothermal Energy**	Applicable to both open cast mine and underground mine	Temperature of water > 175 degree, for electricity generation purpose	For setting up district heaters or Geothermal Heat Pump, lower temperatures of 20 °C can also be used	Presence of power transmission infrastructure includes transformer, switch gear, transmission lines, substations, switchyard, grid connection, infrastructure, anchor system, control system and communication infrastructure	factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important				
12	**Recreational Parks**	Applicable to open cast mine only	Ideally the area should be Within 10 km from nearest bus stand, accessible by public transport and private cars. It is better if railway	Land usage of around 10 ha	Nearby population will be an important factor in deciding the footfall	Source of electricity is required to power the set up	The electricity consumption to run the recreational park will depend upon the rides, lighting and other facilities in the park			

S.No.	Repurposing Options	Factors Effecting Suitability								
			stations, airports, are present nearby							
13	**Ecotourism**	Applicable to open cast mine only	Ideally the area should be Within 10 km from nearest bus stand, accessible by public transport and private cars. It is better if railway stations, airports, are present nearby	Land usage of around 10 ha	Nearby population will be an important factor in deciding the footfall	Source of electricity is required to power the set up	The electricity consumption to run the place will depend upon the lighting and other facilities in the area			
14	**Memorial / Museum**	Applicable to both open cast mine and underground mine	Ideally the area should be Within 10 km from nearest bus stand, accessible by public transport and private cars. It is better if railway stations, airports, are present nearby	Land usage of around 10 ha	Nearby population will be an important factor in deciding the footfall	Availability of power	Adequate ventilation should be ensured in case of underground museum or other facility	factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important		
15	**Waste Disposal - Bioreactor Landfill**	Applicable to open cast mine only	Atleast at 5 km distance from major town as the cost of transportation increases with the increase in distance.	Availability of water is subjective to moisture availability	Presence of power transmission infrastructure includes transformer, switch gear, transmission lines, substations, switchyard, grid connection, infrastructure, anchor system, control system and communication infrastructure					
16	**Water Storage & Flood Protection**	Applicable to open cast mine only	Surface area of 1-70 ha and depth of 10 to 100 m	Ideally the PH level should be between 7.5 to 8.5	Biochemical oxygen demand (BOD) should be minimum 4mg/l	Chemical oxygen demand (COD) should be less than 50 mg/l				
17	**Wildlife Habitat**	Applicable to both open cast mine and underground mine	Availability of power for lighting purpose, specially in UG mines	Presence of green cover is required to attract wildlife species.	The area should be protected and minimal human interference has to be there	The noise levels of the area should be low to attract wildlife	Availability of disposal system			
18	**Pisciculture**	Applicable to open cast mine only	Subjective to availability of mine area filled with water	Ideally the PH level should be between 7.5 to 8.5	Biochemical oxygen demand (BOD) should be minimum 4mg/l	Chemical oxygen demand (COD) should be less than 50 mg/l				

S.No.	Repurposing Options	Factors Effecting Suitability									
19	**Horticulture**	Applicable to both open cast mine and underground mine	The land to be utilized is subject to the available area	Water requirement in UG mine is 2020 l/day. Water requirement in OC mine depends on the crop but ranges from 300 mm - 2200 mm for certain plants and 8- 100 l/day for certain plants	Power requirement in UG - 38.8 kWh per kg of produce	factor of safety (FOS) against collapse, determining the range of ground behaviors is particularly important in case of underground mines					

Source : PwC Analyses

25.2. Potential for symbiosis with other repurposing options

In this sub section all the repurposing options have been evaluated to check if more than one options can be adopted at a mine and if there is any synergy that can be created by establishing different options together. The symbiosis is based on the type of mining, land usage, location, presence of water, meteorological factors, depth of mine shaft etc. The table below explains the potential symbiosis between different repurposing options.

Table 73: Potential for symbiosis between repurposing options

Legend

Not applicable (grey) Symbiosis possible (green) Symbiosis needs further evaluation (red)

S. No.	Repurposing options	Pumped storage hydropower	Pumped underground storage hydropower	Compressed air storage	Hydrogen storage	Thermal energy storage	Gravity storage	Co$_2$ storage	Wind energy on mining land	PV on mining land	Floating solar	Geothermal energy	Recreational parks		Ecotourism	Memorial / museum	Waste disposal – bioreactor or landfill	Water storage & flood protection	Wildlife habitat	Pisciculture	Horticulture
1	Pumped Storage Hydropower	Not applicable	Needs further evaluation	Needs further evaluation	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Symbiosis possible	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Symbiosis possible	Symbiosis possible	Needs further evaluation	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Symbiosis possible
2	Pumped Underground Storage Hydropower	Needs further evaluation	Not applicable	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Symbiosis possible	Symbiosis possible	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation
3	Compressed Air Storage	Needs further evaluation	Needs further evaluation	Not applicable	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Symbiosis possible	Symbiosis possible	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation
4	Hydrogen Storage	Needs further evaluation	Needs further evaluation	Needs further evaluation	Not applicable	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation
5	Thermal Energy storage	Symbiosis possible	Needs further evaluation	Symbiosis possible	Needs further evaluation	Not applicable	Needs further evaluation	Needs further evaluation	Symbiosis possible	Symbiosis possible	Needs further evaluation	Needs further evaluation	Symbiosis possible	Symbiosis possible	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Symbiosis possible
6	Gravity Storage	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Not applicable	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation
7	CO_2 Storage	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Not applicable	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation
8	Wind Energy on Mining Land	Symbiosis possible	Symbiosis possible	Symbiosis possible	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Not applicable	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Symbiosis possible
9	PV on Mining Land	Symbiosis possible	Symbiosis possible	Symbiosis possible	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Symbiosis possible	Not applicable	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation
10	Floating Solar	Needs further evaluation	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Not applicable	Needs further evaluation	Needs further evaluation	Symbiosis possible	Symbiosis possible	Needs further evaluation	Needs further evaluation	Symbiosis possible	Needs further evaluation	Symbiosis possible	Needs further evaluation
11	Geothermal Energy	Needs further evaluation	Symbiosis possible	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Not applicable	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation	Needs further evaluation

S. No.	Repurposing options	Pumped storage hydropower	Pumped underground storage hydropower	Compressed air storage	Hydrogen storage	Thermal energy storage	Gravity storage	Co_2 storage	Wind energy on mining land	PV on mining land	Floating solar	Geothermal energy	Recreational parks		Ecotourism	Memorial / museum	Waste disposal - bioreactor or landfill	Water storage & flood protection	Wildlife habitat	Pisciculture	Horticulture
12	Recreational Parks																				
13	Ecotourism																				
14	Memorial / Museum																				
15	Waste Disposal - Bioreactor or Landfill																				
16	Water Storage & Flood Protection																				
17	Wildlife Habitat																				
18	Pisciculture																				
19	Horticulture																				

Source : PwC Analyses

26. Mapping of Repurposing Option for Indian Coal Mines

There are nine (09) states in India in which coal mines are present. The type of mining adopted can be divided into three categories namely open cast, underground and mixed in which both types of methods have been used for excavation. It was found that amongst the nine states Jharkhand has the greatest number of coal mines which could suggest that Jharkhand can be the best place to start with repurposing of coal mines in India. Other factors also have to be weight in. Total number of coal mines identified in India are 475 out of which 240 are open cast, 202 are underground, and 27 are mixed type of mines.

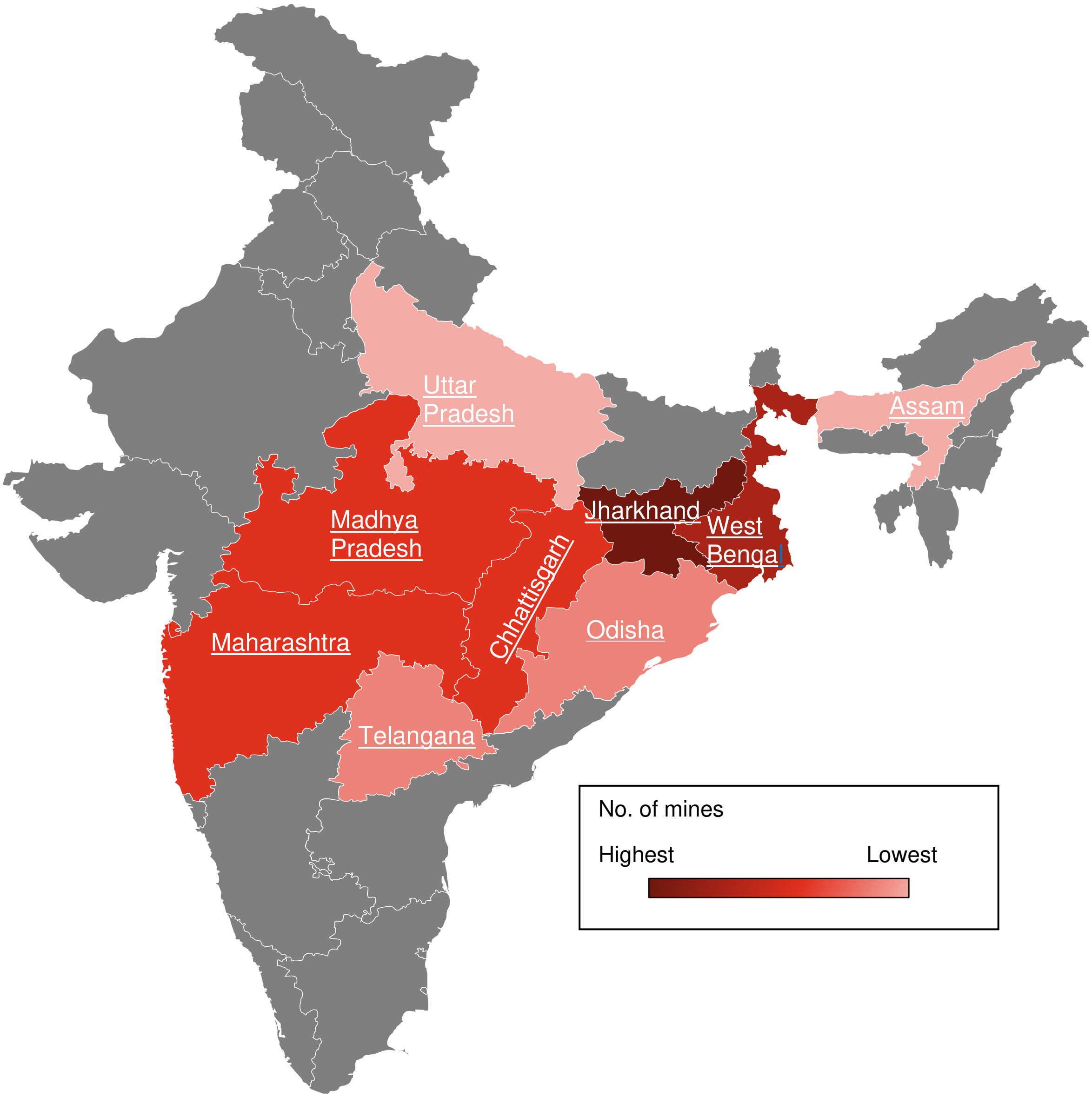
Table 74: State wise distribution of coal mines

State	Mixed	OC	UG	Unidentified	Grand Total
Assam		3	1		4
Chhattisgarh	6	23	26	2	57
Jharkhand	10	89	31	1	131
Madhya Pradesh	2	19	42		63
Maharashtra	1	39	21		61
Odisha		24	8	3	35
Telangana		19	27		46
Uttar Pradesh		4			4
West Bengal	8	20	46		74
Grand Total	**27**	**240**	**202**	**6**	**475**

Source: PwC analyses of energy map of India by NITI Aayog & ISRO

For the ease of understanding the mines have been plotted on the map of India as given below. In the later sections the state wise plotting of the coal mines has been done so that the penetration till district level can be achieved and subsequently we can map the repurposing potential of the coal mines present in each state. One may click on the state names present on the map of India to reach out to the section containing the coal mine data of the respective state.

Figure 102: Indian states having coal mines



Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1. State wise mapping of coal mines in nine states

The data of the coal fields and coal mines have been extracted from the energy map of India prepared by NITI Aayog and ISRO[374]. The data extracted contains information about state, district, coal mine, coalfield, type of mine, owner, coalfield wise proven, probable and inferred reserve. All the state maps used in the subsequent subsections have been taken from the following source: link.

26.1.1. Coal mines in Assam

Four coal mines have been identified in assam and the same have been mapped below on the map of the state.

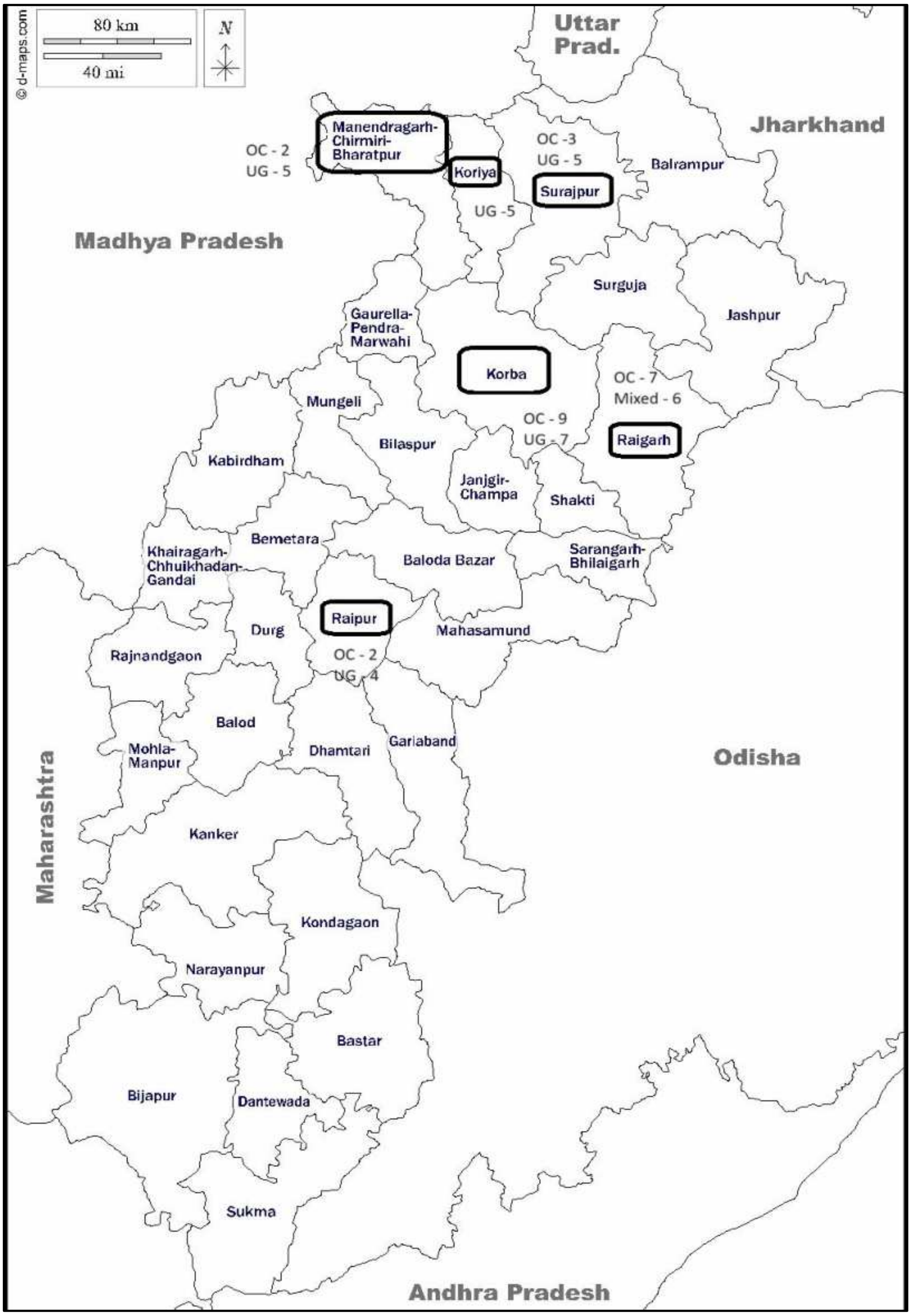
Figure 103: Coal mines in Assam

Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.2. Coal mines in Chhattisgarh

57 coal mines have been identified in Chhattisgarh out of which 23 are open cast, 26 are underground and 6 are mixed. The map given below consists of the coal mines present in Chhattisgarh.

Figure 104: Coal mines in Chhattisgarh

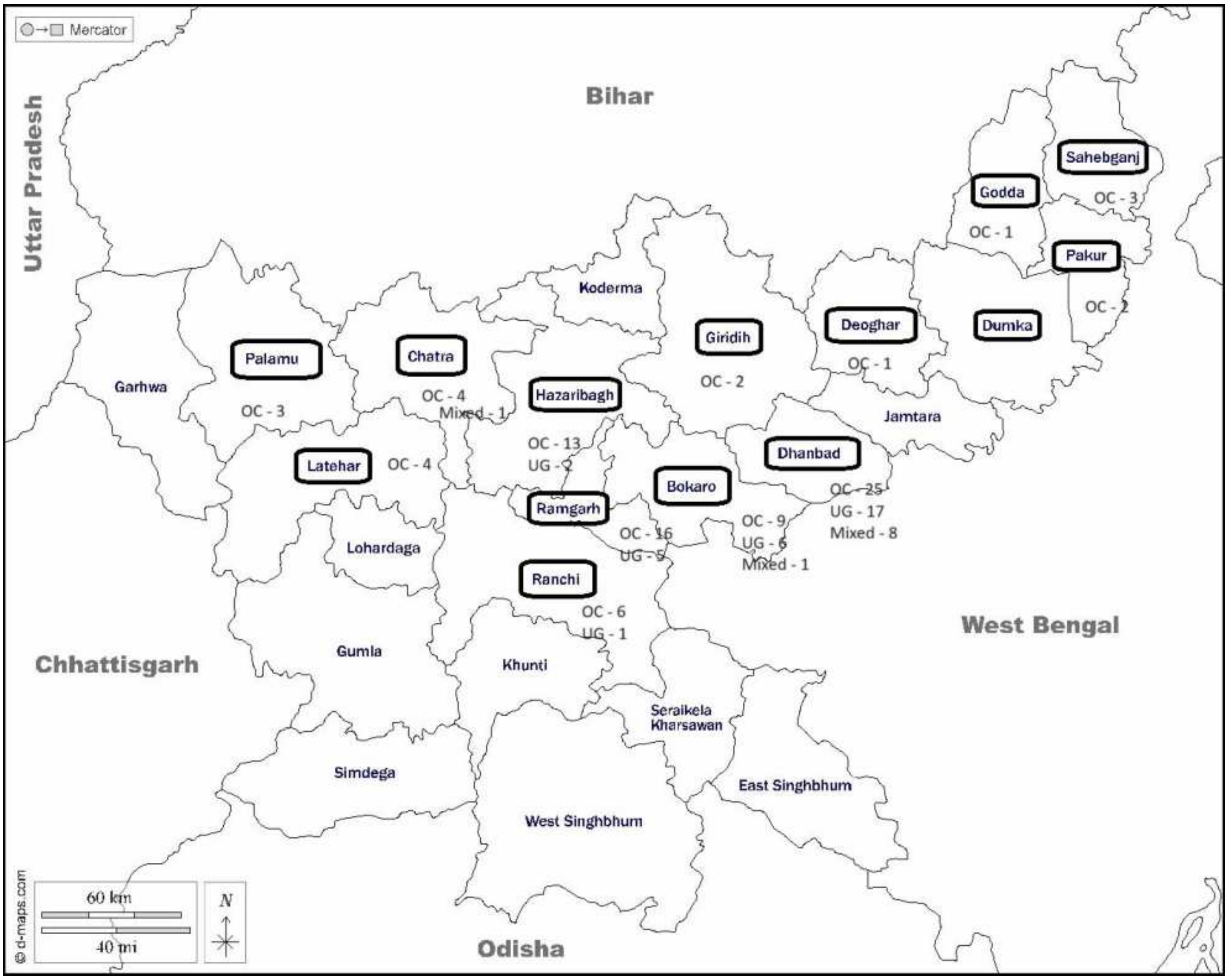


Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.3. Coal mines in Jharkhand

130 coal mines have been identified in Jharkhand out of which 89 mines have been excavated by open cast method of mining, 31 by underground, and 10 by mixed method of mining. The district wise mapping of the same is given below.

Figure 105: Coal mines in Jharkhand

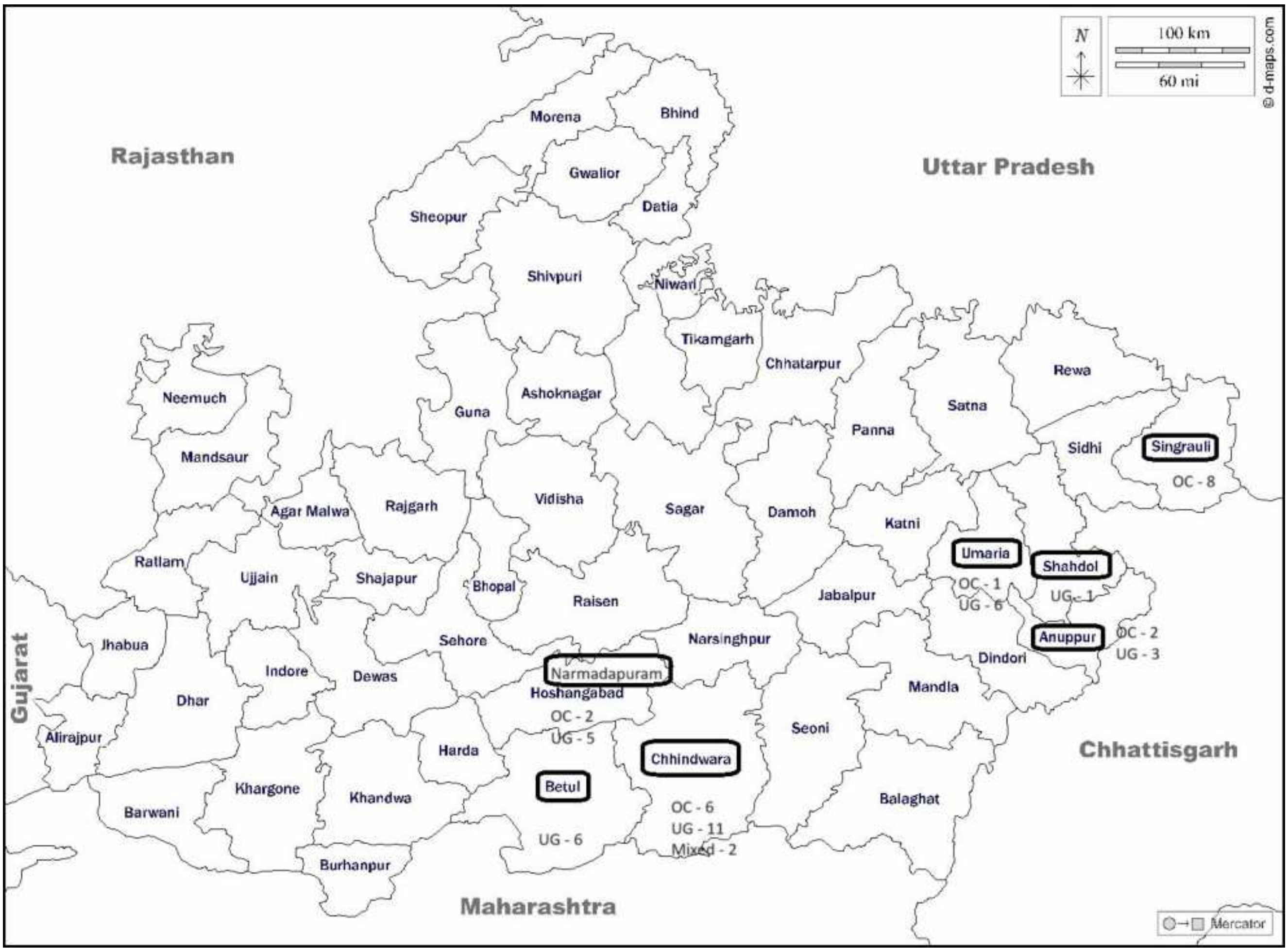


Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.4. Coal mines in Madhya Pradesh

63 coal mines have been identified in Madhya Pradesh out of which 19 are open cat coal mines, 42 are underground and 2 are mixed. The coal mine present in Madhya Pradesh have been mapped in the map given below.

Figure 106: Coal mines in Madhya Pradesh

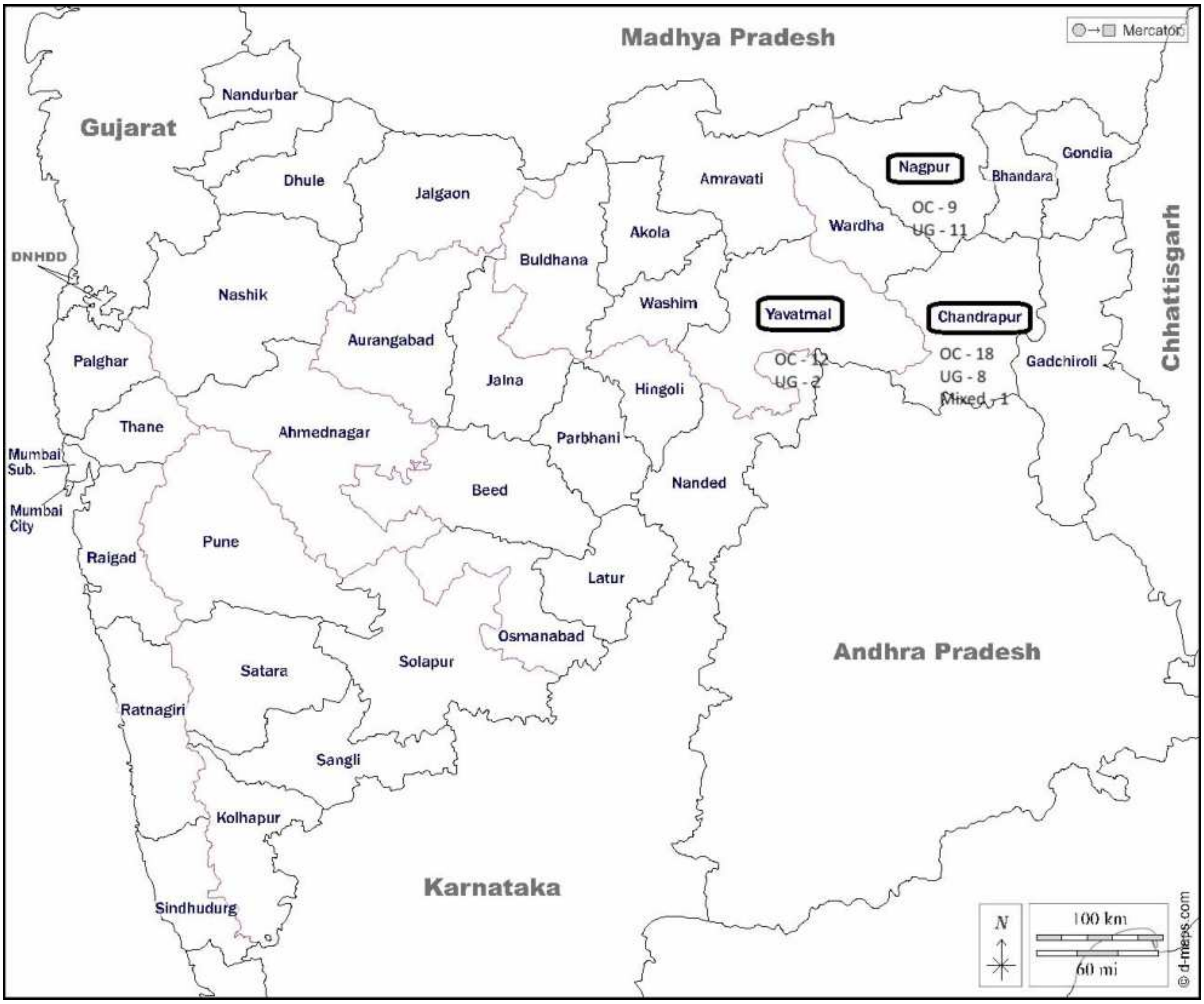


Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.5. Coal mines in Maharashtra

61 coal mines have been identified in Maharashtra out of which 39 mines are open cast, 21 mines are underground, 1 is of mixed type. The coal mines in Maharashtra have been mapped below.

Figure 107: Coal mines in Maharashtra

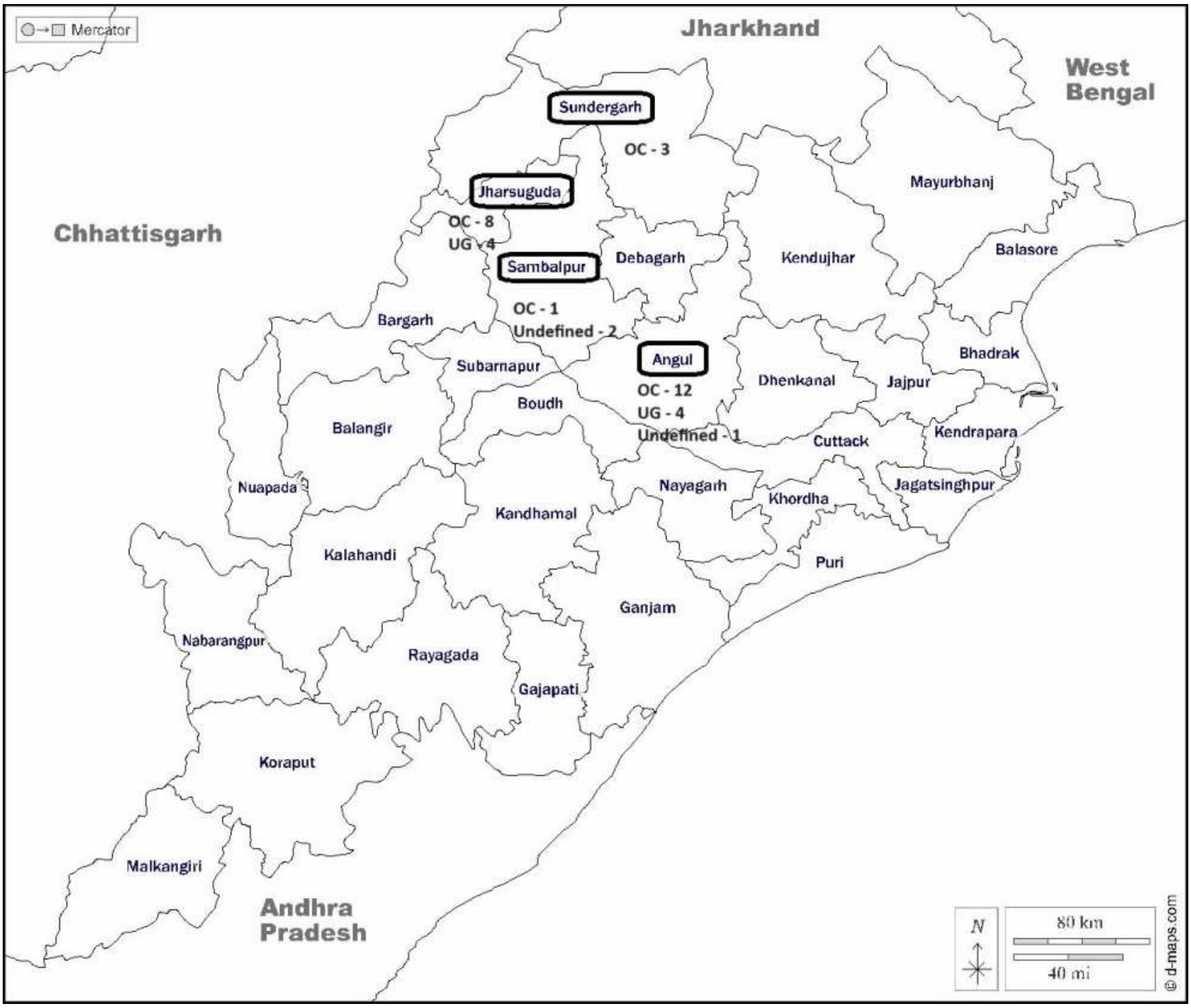


Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.6. Coal mines in Odisha

35 coal mines have been identified out of which 24 are open cast, 8 are underground, and 3 are yet to be defined. The coal mines in Odisha have been mapped below.

Figure 108: Coal mines in Odisha

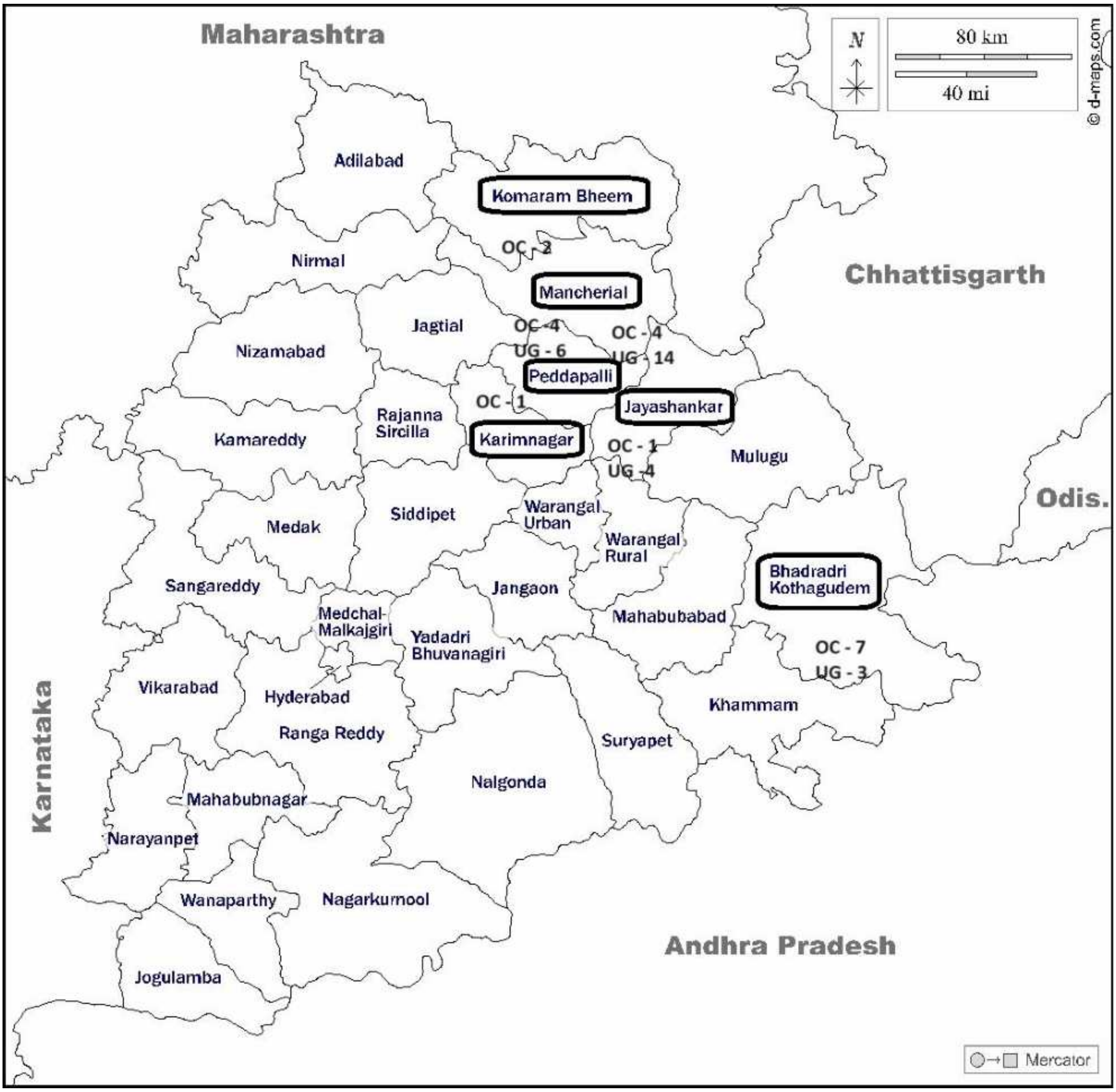


Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.7. Coal mines in Telangana

46 coal mines have been identified out of which 19 are open cast and 27 are underground. The coal mines in Telangana have been mapped below.

Figure 109: Coal mines in Telangana



Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.8. Coal mines in Uttar Pradesh

Four open cast coal mines have been identified in Uttar Pradesh and the same has been mapped below.

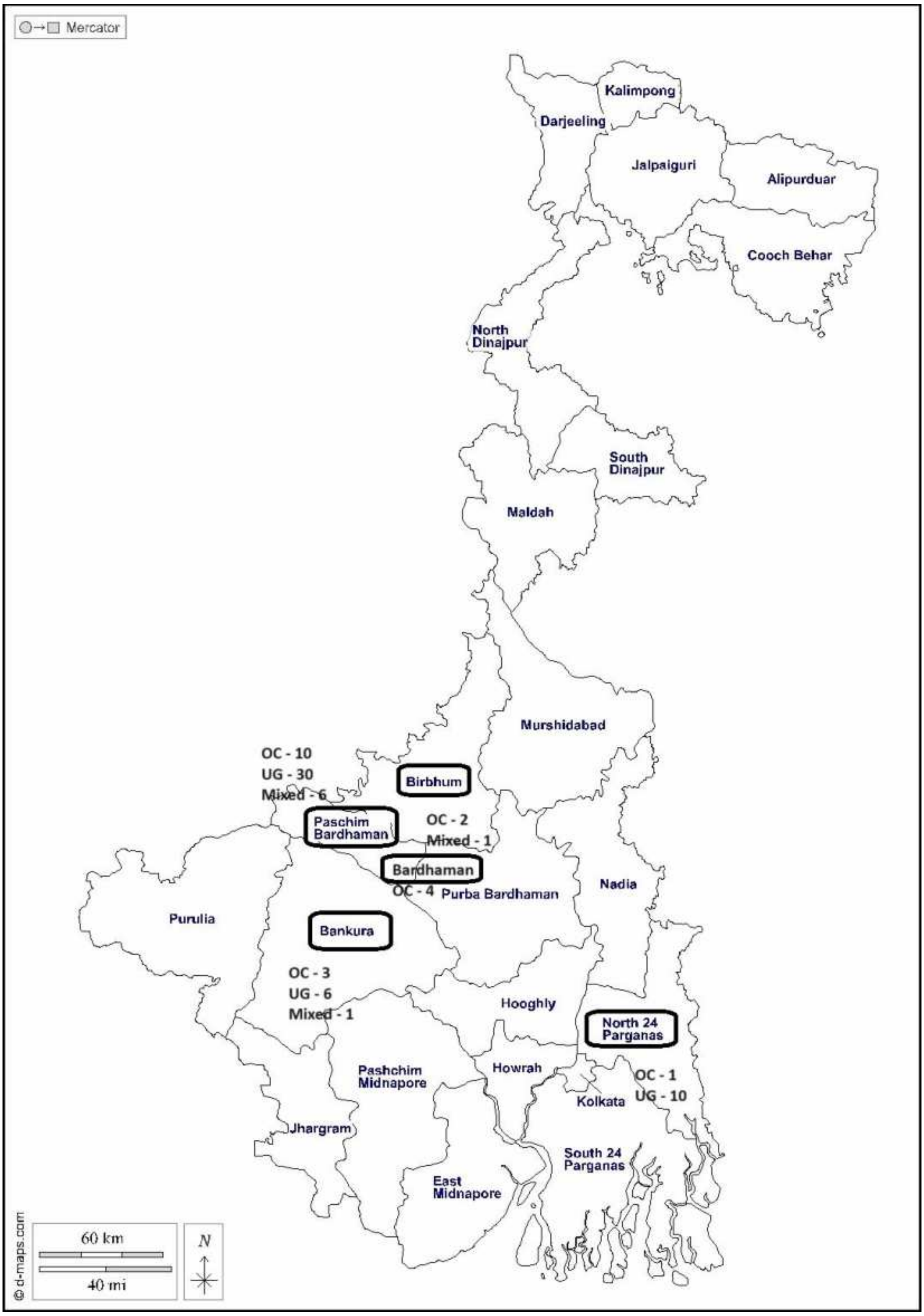
Figure 110: Coal mines in Uttar Pradesh

Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.1.9. Coal mines in West Bengal

74 coal mines have been identified in west Bengal out of which 20 are open cast, 46 are underground, and 8 are of mixed type. All these mines have been mapped below.

Figure 111: Coal mines in West Bengal



Source: PwC analyses of energy map of India by NITI Aayog & ISRO

26.2. Categorization of coal mines in India

The applicability of all the discussed repurposing options depends on various factors that have been identified in the repurposing matrix. PwC has categorized the mines in five categories on the basis of mining method, depth, area and gassiness of mine and have identified the repurposing options that can be applicable in different categories of mine. The table below summarizes categorization of mines based on different parameters. PwC has assigned various repurposing options to these different categories of mines in the sub sections of this report.

Table 75: Categorization of coal mines

Mine type	OC/UG	Depth (m)	Area (Ha)	Gassiness of mine
Category A	OC	<100	<200	NA
Category B	OC	>100	>200	NA
Category C	UG	<500	NA	Degree 1
Category D	UG	>500	NA	Degree 1
Category E	UG	>0	NA	Degree 2 / Degree 3

Source: PwC Analyses

It was observed that most of the proved reserves of coal present in the Indian coal fields are lying within the range of (0-300) meters in Inda and such type of mines are most prominent in India. A list of coal mines along with the proved reserve percentage is given in the appendices.

26.3. Mapping of repurposing options

We have identified the repurposing options that are applicable to different categories of mines as shown in the table below. The type of mine falling under these categories can be checked for the repurposing options given in the table below.

Table 76: Applicability of repurposing options as per mine category

Category A	Category B	Category C	Category D	Category E
Thermal energy storage	Pumped storage hydropower	Pumped underground storage hydropower	Pumped underground storage hydropower	Compressed air storage
Wind energy	Thermal energy storage	Compressed air storage	Compressed air storage	Hydrogen storage
Photo voltaic	Wind energy	Hydrogen storage	Hydrogen storage	
Floating solar	Photo voltaic	Geothermal energy	Gravity storage	
Recreational parks	Floating solar	Memorial / museum	CO_2 storage	
Ecotourism	Recreational parks	Wildlife habitat	Geothermal energy	

Category A	Category B	Category C	Category D	Category E
Memorial/ Museum	Ecotourism	Horticulture	Memorial / museum	
Waste disposal – bioreactor landfill	Memorial/ Museum		Wildlife habitat	
Water storage and flood protection	Waste disposal – bioreactor landfill		Horticulture	
Wildlife habitat	Water storage and flood protection			
Pisciculture	Wildlife habitat			
Horticulture	Pisciculture			
	Horticulture			

Source: PwC analyses

27. Way Forward

The repurposing of coal mines in India is a complex challenge, and there are different roles that various stakeholders like government, financers, mining players, and academic institutions have to play for repurposing of abandoned/closed/discontinued mines. Below are some of the initiatives that different institutions may take to fast track this process.

1. **Government**
   a. Govt. to prepare policy framework for Repurposing of coal mines.
   b. Repurposing should be added as a chapter in Mine Closure Plan,
   c. Provisions for linking DMF with repurposing initiative for viability gap funding may be explored.
   d. Infrastructure assessment in the region for repurposing may be carried out to make the options more lucrative.
2. **Financers**
   a. Lending institutions such as Banks, NBFCs to create funding mechanism such as InvITs, Mutual Fund etc.
   b. Multilateral funding agencies & development banks such as GIZ, World Bank, ADB, IMF to prepare viability assessment for repurposing options under green finance.
   c. Equity investors to reassess the potential synergy of multiple repurposing options.
3. **Mining players**
   a. Geotechnical assessment of existing operational mines for potential repurposing options may be conducted.
   b. Reassessment of the financial viability of existing mining operations considering the potential of deployment of suitable repurposing alternatives post exhaustion of mineral reserves.
   c. Consultation with global technology solution providers in energy space.
4. **Academic Institution**
   a. Promote research & scientific studies in academic institution with multidisciplinary departments to evaluate the repurposing options in mines.
   b. Undertake the preparation of Detailed Project Report (DPR) for repurposing alternatives options for mines and their synergy potential.
   c. Promote communication campaign and community awareness.

Appendices

A.1. Coal mines in India

Table 77: List of coal mines with details

S. No.	State	District	Coal mine	Coalfield	Location	Type	Owner	Proved reserve percentage within (0-300m)	Proved reserve percentage within (300-600m)	Proved reserve percentage within (600-1200m)
1	Odisha	Angul	Chendipara	Talcher	Bharatpur	OC	MCL	85.59%	13.43%	9.98%
2	Odisha	Angul	Hingula	Talcher	Hingula	OC	MCL	85.59%	13.43%	9.98%
3	Odisha	Angul	Kaniha	Talcher	Kaniha	OC	MCL	59%	13.43%	9.98%
4	Odisha	Angul	Balram	Talcher	Hingula	OC	MCL	85.59%	13.43%	9.98%
5	Odisha	Angul	Bharatpur	Talcher	Bharatpur	OC	MCL	85.59%	13.43%	9.98%
6	Odisha	Angul	Ananta	Talcher	Jagannath	OC	MCL	85.59%	13.43%	9.98%
7	Odisha	Angul	Jagannath	Talcher	Jagannath	OC	MCL	85.59%	13.43%	9.98%
8	Odisha	Angul	Bhubaneshwar	Talcher	Jagannath	OC	MCL	85.59%	13.43%	9.98%
9	Odisha	Angul	Lingaraj	Talcher	Lingaraj	OC	MCL	85.59%	13.43%	9.98%
10	Odisha	Angul	Deulbera	Talcher	Talcher	UG	MCL	85.59%	13.43%	9.98%
11	Odisha	Angul	Handidhua	Talcher	Talcher	UG	MCL	85.59%	13.43%	9.98%
12	Odisha	Angul	Nandira	Talcher	Talcher	UG	MCL	85.59%	13.43%	9.98%
13	Odisha	Angul	Talcher	Talcher	Talcher	UG	MCL	85.59%	13.43%	9.98%
14	Odisha	Jharsuguda	Orient Mine No. 4	IB_Valley	Orient	UG	MCL	90.08%	9.92%	0%
15	Odisha	Jharsuguda	Orient Mine No. 3	IB_Valley	Orient	UG	MCL	90.08%	9.92%	0%
16	Odisha	Jharsuguda	Orient Mine No. 1&2	IB_Valley	Orient	UG	MCL	90.08%	9.92%	0%
17	Odisha	Jharsuguda	Hirakhand Bundia Incline	IB_Valley	Orient	UG	MCL	90.08%	9.92%	0%

18	Odisha	Sambalpur	Mandakini	NA	NA	OC	Mandakini Exploration & Mining Ltd			
19	Odisha	Angul	Naini	NA	NA	OC	Singareni Collieries Co Ltd.			
20	Odisha	Angul	Utkal-E	NA	NA	OC	NALCO			
21	Odisha	Angul	Utkal-C	NA	NA		Monnet Power Company Ltd			
22	Odisha	Angul	Utkal-D	NA	NA	OC	NALCO			
23	Odisha	Sambalpur	Talabira-I	NA	NA		GMR Chhattisgarh Energy Ltd.			
24	Odisha	Sambalpur	Talabira-II & III	NA	NA		Neyvilli Lignite Corp. Ltd			
25	Odisha	Sundargarh	Dulanga	NA	NA	OC	NTPC ltd			
26	Odisha	Sundargarh	Manohapur	NA	NA	OC	Odisha Coal & Power Ltd			
27	Odisha	Sundargarh	Dipside Manoharpur	NA	NA	OC	Odisha Coal & Power Ltd			
28	Odisha	Jharsuguda	Basundhara	IB_Valley	Basundhara	OC	MCL	90.08%	9.92%	0%
29	Odisha	Jharsuguda	Garjanbahal	IB_Valley	Basundhara	OC	MCL	90.08%	9.92%	0%
30	Odisha	Jharsuguda	Kulda	IB_Valley	Basundhara	OC	MCL	90.08%	9.92%	0%
31	Odisha	Jharsuguda	Lakhanpur	IB_Valley	Lakhanpur	OC	MCL	90.08%	9.92%	0%
32	Odisha	Jharsuguda	Lilari	IB_Valley	Lakhanpur	OC	MCL	90.08%	9.92%	0%
33	Odisha	Jharsuguda	Belpahar	IB_Valley	Lakhanpur	OC	MCL	90.08%	9.92%	0%
34	Odisha	Jharsuguda	Lajkura	IB_Valley	IB_Valley	OC	MCL	90.08%	9.92%	0%
35	Odisha	Jharsuguda	Samaleswari	IB_Valley	IB_Valley	OC	MCL	90.08%	9.92%	0%
36	Assam	Tinsukia	Tipong	Makum	Margherita	UG	NEC			

37	Assam	Tinsukia	Tirap OC P Phase II	Makum	Margherita	OC	NEC			
38	Assam	Tinsukia	Ledo OCP	Makum	Margherita	OC	NEC			
39	Assam	Tinsukia	Tilak east, West and Namdang	Makum	Margherita	OC	NEC			
40	West Bengal	Bankura	Barjora	NA	NA	OC	West Bengal Power Development Corp Ltd			
41	West Bengal	Bankura	Trans Damodar	NA	NA	OC	The Durgapur Project Limited			
42	West Bengal	Birbhum	Kharga Joydev	NA	NA	Mixed	West Bengal Power Development Corp Ltd			
43	West Bengal	Bankura	Ardhagram	NA	NA	OC	DC-OCL Iron & Steel Ltd			
44	West Bengal	Birbhum	Gangaramchak, Gangaramchak Bhadulia	NA	NA	OC	West Bengal Power Development Corp Ltd			
45	West Bengal	Burdwan	Sarisatolli	NA	NA	OC	CESC Ltd			
46	West Bengal	Burdwan	Tara East & West	NA	NA	OC	West Bengal Power Development Corp Ltd			
47	West Bengal	Birbhum	Kasta East	NA	NA	OC	West Bengal Power Development Corp Ltd			

48	West Bengal	North 24 Parganas	Parbelia	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
49	West Bengal	North 24 Parganas	Dubeswari	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
50	West Bengal	North 24 Parganas	Sodepur R	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
51	West Bengal	North 24 Parganas	ChinaKuri III	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
52	West Bengal	North 24 Parganas	Bejdih	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
53	West Bengal	North 24 Parganas	Methani	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
54	West Bengal	North 24 Parganas	Patmohona	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
55	West Bengal	North 24 Parganas	Dhemomain Pit	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
56	West Bengal	North 24 Parganas	Dhemomain Incline	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
57	West Bengal	North 24 Parganas	Narsumuda	Raniganj	Sodepur	UG	ECL	77.99%	17.90%	4.11%
58	West Bengal	North 24 Parganas	Begunia	Raniganj	Salanpur	OC	ECL	77.99%	17.90%	4.11%
59	West Bengal	Burdwan	Damagoria	Jharia*	C.V.	OC	BCCL		90.92%	9.03%
60	West Bengal	Paschim Bardhaman	Bonjemehari OC & UG	Raniganj	Salanpur	OC	ECL	77.99%	17.90%	4.11%
61	West Bengal	Paschim Bardhaman	Dabor UG	Raniganj	Salanpur	OC	ECL	77.99%	17.90%	4.11%
62	West Bengal	Paschim Bardhaman	Mohanpur OCP	Raniganj	Salanpur	OC	ECL	77.99%	17.90%	4.11%
63	West Bengal	Paschim Bardhaman	Itapara OC Patch	Raniganj	Salanpur	OC	ECL	77.99%	17.90%	4.11%

64	West Bengal	Paschim Bardhaman	Gouandih UG & OC	Raniganj	Salanpur	OC	ECL	77.99%	17.90%	4.11%
65	West Bengal	Paschim Bardhaman	Bhanora W/B UG & OC Patch(H)	Raniganj	Sripur	Mixed	ECL	77.99%	17.90%	4.11%
66	West Bengal	Paschim Bardhaman	Kaliphari UG	Raniganj	Sripur	OC	ECL	77.99%	17.90%	4.11%
67	West Bengal	Paschim Bardhaman	Ningah Colliery	Raniganj	Sripur	UG	ECL	77.99%	17.90%	4.11%
68	West Bengal	Bankura	Chapuikhas Colliery	Raniganj	Satgram	UG	ECL	77.99%	17.90%	4.11%
69	West Bengal	Bankura	Satgram Project	Raniganj	Satgram	UG	ECL	77.99%	17.90%	4.11%
70	West Bengal	Bankura	Satgram Incline	Raniganj	Satgram	UG	ECL	77.99%	17.90%	4.11%
71	West Bengal	Bankura	Kalidaspur Project	Raniganj	Satgram	UG	ECL	77.99%	17.90%	4.11%
72	West Bengal	Bankura	Nimcha UG & OC (Amkola) (H)	Raniganj	Satgram	Mixed	ECL	77.99%	17.90%	4.11%
73	West Bengal	Bankura	J K Nagar	Raniganj	Satgram	UG	ECL	77.99%	17.90%	4.11%
74	West Bengal	Bankura	Pure Searsole	Raniganj	Satgram	UG	ECL	77.99%	17.90%	4.11%
75	West Bengal	Paschim Bardhaman	Amritnagar	Raniganj	Kunustoria	UG	ECL	77.99%	17.90%	4.11%
76	West Bengal	Paschim Bardhaman	Mahabir UG	Raniganj	Kunustoria	OC	ECL	77.99%	17.90%	4.11%
77	West Bengal	Paschim Bardhaman	North Searsole	Raniganj	Kunustoria	OC	ECL	77.99%	17.90%	4.11%
78	West Bengal	Paschim Bardhaman	Kunustoria	Raniganj	Kunustoria	UG	ECL	77.99%	17.90%	4.11%
79	West Bengal	Paschim Bardhaman	Bansra	Raniganj	Kunustoria	Mixed	ECL	77.99%	17.90%	4.11%
80	West Bengal	Paschim Bardhaman	Belbaid	Raniganj	Kunustoria	UG	ECL	77.99%	17.90%	4.11%
81	West Bengal	Paschim Bardhaman	Parasea	Raniganj	Kunustoria	UG	ECL	77.99%	17.90%	4.11%

82	West Bengal	Paschim Bardhaman	New Kenda UG & OC (H)	Raniganj	Kenda	Mixed	ECL	77.99%	17.90%	4.11%
83	West Bengal	Paschim Bardhaman	Lower Kenda	Raniganj	Kenda	UG	ECL	77.99%	17.90%	4.11%
84	West Bengal	Paschim Bardhaman	Chora 7&9 Pit	Raniganj	Kenda	UG	ECL	77.99%	17.90%	4.11%
85	West Bengal	Paschim Bardhaman	Bahula	Raniganj	Kenda	UG	ECL	77.99%	17.90%	4.11%
86	West Bengal	Paschim Bardhaman	CL Jambad	Raniganj	Kenda	UG	ECL	77.99%	17.90%	4.11%
87	West Bengal	Paschim Bardhaman	Chora Inc Shankarpur & Bonbahal	Raniganj	Kenda	UG	ECL	77.99%	17.90%	4.11%
88	West Bengal	Paschim Bardhaman	Chora 10 Pit	Raniganj	Kenda	UG	ECL	77.99%	17.90%	4.11%
89	West Bengal	Paschim Bardhaman	Siduli	Raniganj	Kenda	UG	ECL	77.99%	17.90%	4.11%
90	West Bengal	Paschim Bardhaman	Jambad OC	Raniganj	Kajora	OC	ECL	77.99%	17.90%	4.11%
91	West Bengal	Paschim Bardhaman	Jambad UG	Raniganj	Kajora	UG	ECL	77.99%	17.90%	4.11%
92	West Bengal	Paschim Bardhaman	Madhabpu UG & Madhabpur OC	Raniganj	Kajora	Mixed	ECL	77.99%	17.90%	4.11%
93	West Bengal	Paschim Bardhaman	Nabakjora	Raniganj	Kajora	UG	ECL	77.99%	17.90%	4.11%
94	West Bengal	Paschim Bardhaman	Parascle(West)	Raniganj	Kajora	UG	ECL	77.99%	17.90%	4.11%
95	West Bengal	Paschim Bardhaman	Parascle(East)	Raniganj	Kajora	UG	ECL	77.99%	17.90%	4.11%
96	West Bengal	Paschim Bardhaman	Madhusudanpur 7 Pit & Incline	Raniganj	Kajora	UG	ECL	77.99%	17.90%	4.11%

97	West Bengal	Paschim Bardhaman	Khas Kajora	Raniganj	Kajora	UG	ECL	77.99%	17.90%	4.11%
98	West Bengal	Paschim Bardhaman	Central Kajora	Raniganj	Kajora	UG	ECL	77.99%	17.90%	4.11%
99	West Bengal	Paschim Bardhaman	Pandaveswar	Raniganj	Pandaveswar	UG	ECL	77.99%	17.90%	4.11%
100	West Bengal	Paschim Bardhaman	Dalurbandh UG&OC	Raniganj	Pandaveswar	UG	ECL	77.99%	17.90%	4.11%
101	West Bengal	Paschim Bardhaman	Khottadih UG	Raniganj	Pandaveswar	UG	ECL	77.99%	17.90%	4.11%
102	West Bengal	Paschim Bardhaman	Khottadih OC	Raniganj	Pandaveswar	OC	ECL	77.99%	17.90%	4.11%
103	West Bengal	Paschim Bardhaman	Madhaipur UG &OC Patch	Raniganj	Pandaveswar	Mixed	ECL	77.99%	17.90%	4.11%
104	West Bengal	Paschim Bardhaman	Manderboni & S Samal Amal. Mine	Raniganj	Pandaveswar	UG	ECL	77.99%	17.90%	4.11%
105	West Bengal	Paschim Bardhaman	Sankarpur	Raniganj	Bankola	UG	ECL	77.99%	17.90%	4.11%
106	West Bengal	Paschim Bardhaman	Khandra	Raniganj	Bankola	UG	ECL	77.99%	17.90%	4.11%
107	West Bengal	Paschim Bardhaman	Bankola	Raniganj	Bankola	UG	ECL	77.99%	17.90%	4.11%
108	West Bengal	Paschim Bardhaman	Kumardih A	Raniganj	Bankola	UG	ECL	77.99%	17.90%	4.11%
109	West Bengal	Paschim Bardhaman	Shyamsunderpur	Raniganj	Bankola	UG	ECL	77.99%	17.90%	4.11%
110	West Bengal	Paschim Bardhaman	Tilaboni	Raniganj	Bankola	UG	ECL	77.99%	17.90%	4.11%
111	West Bengal	Paschim Bardhaman	Nakrakonda-Kumardih B	Raniganj	Bankola	Mixed	ECL	77.99%	17.90%	4.11%

112	West Bengal	Paschim Bardhaman	Jhanjra Project	Raniganj	Jhanjhra	UG	ECL	77.99%	17.90%	4.11%
113	West Bengal	Burdwan	Sonerpur Bazari I OCP	Raniganj	Sonerpur Bazari	OC	ECL	77.99%	17.90%	4.11%
114	Jharkhand	Godda	Jitpur	NA	NA	OC	Adani Power Ltd			
115	Jharkhand	Pakur	Pachhwara Central	NA	NA	OC	Punjab State Power Corp Ltd			
116	Jharkhand	Pakur	Pachhwara North	NA	NA	OC	West Bengal Power Development Corp Ltd			
117	Jharkhand	Dumka	Saharpur Jamarpani	NA	NA		UP Rajya Vidyut Utpadan Ltd			
118	Jharkhand	Sahebganj	Rajmahal	Hura	Rajmahal	OC	ECL			
119	Jharkhand	Sahebganj	Hurra C	Hura	Rajmahal	OC	ECL			
120	Jharkhand	Sahebganj	Simlong	Chuperbita	Rajmahal	OC	ECL			
121	Jharkhand	Deoghar	Chitra	Saharjuri	SP Mines	OC	ECL			
122	Jharkhand	Giridih	Kabribad	Giridih	Giridi	OC	ECL			
123	Jharkhand	Giridih	Giridih	Giridih	Giridi	OC	ECL			
124	Jharkhand	Chatra	Rajdhara	Daltonganj	Rajdhara	OC	CCL	100%		
125	Jharkhand	Palamu	Kathautia	NA	NA	OC	Hindalco Ind Ltd			
126	Jharkhand	Palamu	Lohari	NA	NA	OC	Aranya Mines Pvt Ltd			
127	Jharkhand	Palamu	Meral	NA	NA	OC	Tirumala Industries Ltd			

128	Jharkhand	Latehar	Tubed	NA	NA	OC	Damodar Valley Corporation			
129	Jharkhand	Latehar	Rajbar D & E	NA	NA	OC	Tenughat Vidyut Nigam Ltd			
130	Jharkhand	Latehar	Banhardih	NA	NA	OC	Jharkhand Urja Utpadan Ltd			
131	Jharkhand	Latehar	Ganeshpur	NA	NA	OC	GMR Chhasttisgarh Energy Ltd.			
132	Jharkhand	Chatra	Tetariakhar	North Karanpura	Rajdhara	OC	CCL	88.19%	10.93%	0.88%
133	Jharkhand	Chatra	Piparwar	North Karanpura	Piparwar	OC	CCL	88.19%	10.93%	0.88%
134	Jharkhand	Chatra	Ashoka	North Karanpura	Piparwar	OC	CCL	88.19%	10.93%	0.88%
135	Jharkhand	Ranchi	Rohini	North Karanpura	N.K.	OC	CCL	88.19%	10.93%	0.88%
136	Jharkhand	Ranchi	Purandih	North Karanpura	N.K.	OC	CCL	88.19%	10.93%	0.88%
137	Jharkhand	Ranchi	Dakra	North Karanpura	N.K.	OC	CCL	88.19%	10.93%	0.88%
138	Jharkhand	Ranchi	KDH	North Karanpura	N.K.	OC	CCL	88.19%	10.93%	0.88%
139	Jharkhand	Ranchi	Churi	North Karanpura	N.K.	UG	CCL	88.19%	10.93%	0.88%
140	Jharkhand	Ranchi	Amarpali	North Karanpura	M & A	OC	CCL	88.19%	10.93%	0.88%
141	Jharkhand	Ranchi	Magadh	North Karanpura	M & A	OC	CCL	88.19%	10.93%	0.88%
142	Jharkhand	Chatra-Hazaribagh	Brinda and Sasai	NA	NA	Mixed	Usha Martin Ltd			
143	Jharkhand	Hazaribagh	Chatti Bariatu	NA	NA	OC	NTPC ltd			
144	Jharkhand	Hazaribagh	Chatti Bariatu South	NA	NA	OC	NTPC ltd			

145	Jharkhand	Hazaribagh	Dumri	NA	NA	OC	Hindalco Ind Ltd			
146	Jharkhand	Hazaribagh	Kerandari	NA	NA	OC	NTPC ltd			
147	Jharkhand	Hazaribagh	Pakri Barwadih	NA	NA	OC	NTPC ltd			
148	Jharkhand	Hazaribagh	Moitra	NA	NA	OC	JSW Steel Ltd			
149	Jharkhand	Hazaribagh	Badam	NA	NA	OC	Bihar State Power Generation Co Ltd			
150	Jharkhand	Hazaribagh	Tokisud North	NA	NA	OC	Essar Power MP Ltd			
151	Jharkhand	Ramgarh	N. Urimari (Birsa)	South Karanpura	Barka-Sayal	OC	CCL	86.35%	13.58%	0.07%
152	Jharkhand	Ramgarh	Urimari OC	South Karanpura	Barka-Sayal	OC	CCL	86.35%	13.58%	0.07%
153	Jharkhand	Ramgarh	Urimari	South Karanpura	Barka-Sayal	UG	CCL	86.35%	13.58%	0.07%
154	Jharkhand	Ramgarh	C. Saunda	South Karanpura	Barka-Sayal	UG	CCL	86.35%	13.58%	0.07%
155	Jharkhand	Ramgarh	Saunda	South Karanpura	Barka-Sayal	UG	CCL	86.35%	13.58%	0.07%
156	Jharkhand	Ramgarh	Bhurkunda OC	South Karanpura	Barka-Sayal	OC	CCL	86.35%	13.58%	0.07%
157	Jharkhand	Ramgarh	Bhurkunda	South Karanpura	Barka-Sayal	UG	CCL	86.35%	13.58%	0.07%
158	Jharkhand	Ramgarh	Giddi A	South Karanpura	Argada	OC	CCL	86.35%	13.58%	0.07%
159	Jharkhand	Ramgarh	Religarha	South Karanpura	Argada	OC	CCL	86.35%	13.58%	0.07%
160	Jharkhand	Ramgarh	Giddi C	South Karanpura	Argada	OC	CCL	86.35%	13.58%	0.07%
161	Jharkhand	Ramgarh	Sirka	South Karanpura	Argada	OC	CCL	86.35%	13.58%	0.07%
162	Jharkhand	Ramgarh	Karma	Ramgarh	Kuju	OC	CCL	98.10%	1.90%	
163	Jharkhand	Ramgarh	Rajrappa	Ramgarh	Rajrappa	OC	CCL	98.10%	1.90%	
164	Jharkhand	Ramgarh	Pindra	West Bokaro	Kuju	OC	CCL	86.65%	13.35%	0%
165	Jharkhand	Ramgarh	Topa and Pindra	West Bokaro	Kuju	OC	CCL	86.65%	13.35%	0%

166	Jharkhand	Ramgarh	Kuju O/S	West Bokaro	Kuju	OC	CCL	86.65%	13.35%	0%
167	Jharkhand	Ramgarh	Hesagara (O/S)	West Bokaro	Kuju	OC	CCL	86.65%	13.35%	0%
168	Jharkhand	Ramgarh	Pundi	West Bokaro	Kuju	OC	CCL	86.65%	13.35%	0%
169	Jharkhand	Ramgarh	Ara	West Bokaro	Kuju	OC	CCL	86.65%	13.35%	0%
170	Jharkhand	Ramgarh	Sarubera/ Chainpur	West Bokaro	Kuju	OC	CCL	86.65%	13.35%	0%
171	Jharkhand	Ramgarh	Sarubera	West Bokaro	Kuju	UG	CCL	86.65%	13.35%	0%
172	Jharkhand	Hazaribagh	Tapin_South	West Bokaro	Hazaribag	OC	CCL	86.65%	13.35%	0%
173	Jharkhand	Hazaribagh	Tapin North O/C	West Bokaro	Hazaribag	OC	CCL	86.65%	13.35%	0%
174	Jharkhand	Hazaribagh	Parej East_O/C	West Bokaro	Hazaribag	OC	CCL	86.65%	13.35%	0%
175	Jharkhand	Hazaribagh	Kedla OC	West Bokaro	Hazaribag	OC	CCL	86.65%	13.35%	0%
176	Jharkhand	Hazaribagh	Jharkhand	West Bokaro	Hazaribag	OC	CCL	86.65%	13.35%	0%
177	Jharkhand	Hazaribagh	Kedla	West Bokaro	Hazaribag	UG	CCL	86.65%	13.35%	0%
178	Jharkhand	Hazaribagh	Laiyo	West Bokaro	Hazaribag	UG	CCL	86.65%	13.35%	0%
179	Jharkhand	Bokaro	Govindpur	East Bokaro	Kathara	OC	CCL	80.14%	12.30%	7.56%
180	Jharkhand	Bokaro	Govindpur	East Bokaro	Kathara	UG	CCL	80.14%	12.30%	7.56%
181	Jharkhand	Bokaro	Kathara O/C	East Bokaro	Kathara	OC	CCL	80.14%	12.30%	7.56%
182	Jharkhand	Bokaro	Jarandih	East Bokaro	Kathara	OC	CCL	80.14%	12.30%	7.56%
183	Jharkhand	Bokaro	Karo SPL	East Bokaro	B & K	UG	CCL	80.14%	12.30%	7.56%
184	Jharkhand	Bokaro	Bokaro	East Bokaro	B & K	OC	CCL	80.14%	12.30%	7.56%
185	Jharkhand	Bokaro	AKK	East Bokaro	B & K	OC	CCL	80.14%	12.30%	7.56%
186	Jharkhand	Bokaro	Karo SPL	East Bokaro	B & K	OC	CCL	80.14%	12.30%	7.56%
187	Jharkhand	Bokaro	AAD	East Bokaro	Dhori	OC	CCL	80.14%	12.30%	7.56%
188	Jharkhand	Bokaro	Kargali	East Bokaro	B & K	UG	CCL	80.14%	12.30%	7.56%
189	Jharkhand	Bokaro	Kargali O/C	East Bokaro	B & K	UG	CCL	80.14%	12.30%	7.56%
190	Jharkhand	Bokaro	Dhori Khas	East Bokaro	Dhori	UG	CCL	80.14%	12.30%	7.56%
191	Jharkhand	Bokaro	Dhori O/C	East Bokaro	Dhori	OC	CCL	80.14%	12.30%	7.56%
192	Jharkhand	Bokaro	Tarmi	East Bokaro	Dhori	OC	CCL	80.14%	12.30%	7.56%
193	Jharkhand	Dhanbad	Amalgamated BOCP Mine	Jharia*	Block II	OC	BCCL		90.92%	9.03%

194	Jharkhand	Dhanbad	Phularitand	Jharia*	Barora	Mixed	BCCL		90.92%	9.03%
195	Jharkhand	Dhanbad	Maheshpur	Jharia*	Govindpur	UG	BCCL		90.92%	9.03%
196	Jharkhand	Dhanbad	Kharkaree	Jharia*	Govindpur	UG	BCCL		90.92%	9.03%
197	Jharkhand	Dhanbad	Muraidih	Jharia*	Barora	OC	BCCL		90.92%	9.03%
198	Jharkhand	Dhanbad	Jogidih	Jharia*	Govindpur	UG	BCCL		90.92%	9.03%
199	Jharkhand	Dhanbad	Govindpur	Jharia*	Govindpur	OC	BCCL		90.92%	9.03%
200	Jharkhand	Dhanbad	New Akash Kinaree	Jharia*	Govindpur	Mixed	BCCL		90.92%	9.03%
201	Jharkhand	Dhanbad	Salanpur	Jharia*	Katras	UG	BCCL		90.92%	9.03%
202	Jharkhand	Dhanbad	Amal. Gazlitand Katras Choitudih Colliery	Jharia*	Katras	OC	BCCL		90.92%	9.03%
203	Jharkhand	Dhanbad	Amal.Keshalpur W Mudidih	Jharia*	Katras	Mixed	BCCL		90.92%	9.03%
204	Jharkhand	Dhanbad	Tetulmari	Jharia*	Sijua	Mixed	BCCL		90.92%	9.03%
205	Jharkhand	Dhanbad	Mudidih	Jharia*	Sijua	UG	BCCL		90.92%	9.03%
206	Jharkhand	Dhanbad	Kankanee	Jharia*	Sijua	OC	BCCL		90.92%	9.03%
207	Jharkhand	Dhanbad	Sendra Bansjora	Jharia*	Sijua	OC	BCCL		90.92%	9.03%
208	Jharkhand	Dhanbad	Nichitpur	Jharia*	Sijua	OC	BCCL		90.92%	9.03%
209	Jharkhand	Dhanbad	E Bassuria	Jharia*	Kusunda	OC	BCCL		90.92%	9.03%
210	Jharkhand	Dhanbad	Gondudih Khaskusunda	Jharia*	Kusunda	OC	BCCL		90.92%	9.03%
211	Jharkhand	Dhanbad	Moonidih Project	Jharia*	Western Jharia	UG	BCCL		90.92%	9.03%
212	Jharkhand	Dhanbad	P.B. Project	Jharia*	P.Balihari	UG	BCCL		90.92%	9.03%
213	Jharkhand	Dhanbad	KB 10/12 Pits UG	Jharia*	P.Balihari	UG	BCCL		90.92%	9.03%
214	Jharkhand	Dhanbad	Bhagaband	Jharia*	P.Balihari	UG	BCCL		90.92%	9.03%
215	Jharkhand	Dhanbad	Gopalichuk	Jharia*	P.Balihari	Mixed	BCCL		90.92%	9.03%
216	Jharkhand	Dhanbad	Kendwadih	Jharia*	P.Balihari	OC	BCCL		90.92%	9.03%
217	Jharkhand	Dhanbad	New Godhur-Kusunda Colliery	Jharia*	Kusunda	OC	BCCL		90.92%	9.03%

218	Jharkhand	Dhanbad	Amalgamated Dhansar - Industry- Colliery	Jharia*	Kusunda	OC	BCCL		90.92%	9.03%
219	Jharkhand	Dhanbad	ENA	Jharia*	Kusunda	OC	BCCL		90.92%	9.03%
220	Jharkhand	Dhanbad	Bastacolla	Jharia*	Bastacolla	UG	BCCL		90.92%	9.03%
221	Jharkhand	Dhanbad	Amal. East Bhagatdih Simlabahal (AEBS) Colliery	Jharia*	Bastacolla	OC	BCCL		90.92%	9.03%
222	Jharkhand	Dhanbad	ROCP	Jharia*	Bastacolla	OC	BCCL		90.92%	9.03%
223	Jharkhand	Dhanbad	Dobari	Jharia*	Bastacolla	OC	BCCL		90.92%	9.03%
224	Jharkhand	Dhanbad	KUYA	Jharia*	Bastacolla	Mixed	BCCL		90.92%	9.03%
225	Jharkhand	Dhanbad	Amal N.T.S.T. Jeenagora Colliery	Jharia*	Lodna	OC	BCCL		90.92%	9.03%
226	Jharkhand	Dhanbad	Bhowrah (north) Colliery	Jharia*	E.Jharia	UG	BCCL		90.92%	9.03%
227	Jharkhand	Dhanbad	Bhowrah South	Jharia*	E.Jharia	Mixed	BCCL		90.92%	9.03%
228	Jharkhand	Dhanbad	Amal. Sudamdih - Patherdih Colliery	Jharia*	E.Jharia	OC	BCCL		90.92%	9.03%
229	Jharkhand	Bokaro	Parbatpur Central	NA	NA	Mixed	Steel Authority of India Ltd			
230	Jharkhand	Bokaro	Sitanala	NA	NA	UG	Steel Authority of India Ltd			
231	Jharkhand	Dhanbad	Tasra	NA	NA	OC	Steel Authority of India Ltd			
232	Jharkhand	Dhanbad	Barmuri OC	Raniganj	Mugma	OC	ECL	77.99%	17.90%	4.11%
233	Jharkhand	Dhanbad	Kumardhubi	Raniganj	Mugma	UG	ECL	77.99%	17.90%	4.11%
234	Jharkhand	Dhanbad	Rajpura OC	Raniganj	Mugma	OC	ECL	77.99%	17.90%	4.11%
235	Jharkhand	Dhanbad	Kapasara UG	Raniganj	Mugma	OC	ECL	77.99%	17.90%	4.11%
236	Jharkhand	Dhanbad	Basantimata-Dahibari Colliery	Jharia*	C.V.	OC	BCCL		90.92%	9.03%

237	Jharkhand	Dhanbad	Lakhimata	Raniganj	Mugma	UG	ECL	77.99%	17.90%	4.11%
238	Jharkhand	Dhanbad	Khoodia	Raniganj	Mugma	UG	ECL	77.99%	17.90%	4.11%
239	Jharkhand	Dhanbad	Shampur-B	Raniganj	Mugma	UG	ECL	77.99%	17.90%	4.11%
240	Jharkhand	Dhanbad	Nirsha OC Patch	Raniganj	Mugma	OC	ECL	77.99%	17.90%	4.11%
241	Jharkhand	Dhanbad	Shampur-A UG	Raniganj	Mugma	OC	ECL	77.99%	17.90%	4.11%
242	Jharkhand	Dhanbad	Hariajam	Raniganj	Mugma	UG	ECL	77.99%	17.90%	4.11%
243	Jharkhand	Dhanbad	Badjna	Raniganj	Mugma	UG	ECL	77.99%	17.90%	4.11%
244	Jharkhand	Dhanbad	Chapapur	Raniganj	Mugma	Mixed	ECL	77.99%	17.90%	4.11%
245	Chhattisgarh	Korba	Chotia	NA	NA	OC	Bhaat Alluminium Company Ltd			
246	Chhattisgarh	Korba	Paturia	NA	NA	OC	Chhattisgarh State Power Generation Company Ltd.			
247	Chhattisgarh	Korba	Gidhmuri	NA	NA	OC	Chhattisgarh State Power Generation Company Ltd.			
248	Chhattisgarh	Korba	Parsa	NA	NA		Rajasthan Rajya Vidyut Utpadan Nigam Ltd			
249	Chhattisgarh	Korba	Parsa East Kansa Basan	NA	NA	OC	Rajasthan Rajya Vidyut Utpadan Nigam Ltd			
250	Madhya Pradesh	Chhindwara	Sail Ghoghri	NA	NA	UG	Relaince Cement Co Pvt Ltd			
251	Chhattisgarh	Raigarh	Talaipalli	NA	NA	Mixed	NTPC ltd			

252	Chhattisgarh	Raigarh	Gare Palma Sector III	NA	NA		Chhattisgarh State Power Generation Company Ltd.			
253	Chhattisgarh	Raigarh	Gare Palma IV - 7	NA	NA	Mixed	Monnet Ispat & Energy Ltd			
254	Chhattisgarh	Raigarh	Gare Palma Sector IV - 8	NA	NA	Mixed	Ambuja Cements Ltd			
255	Chhattisgarh	Raigarh	Gare Palma IV - 5	NA	NA	Mixed	Hindalco Ind Ltd			
256	Chhattisgarh	Raigarh	Gare Palma Sector II	NA	NA	OC	Maharshtra State Power Co Ltd			
257	Chhattisgarh	Raigarh	Gare Palma IV - 4	NA	NA	Mixed	Hindalco Ind Ltd			
258	Chhattisgarh	Raigarh	Gare Palma Sector I	NA	NA	Mixed	Gujarat State Electricity Corp Ltd			
259	Chhattisgarh	Raigarh	Gare Palma Sector IV/1	Mand-Raigarh	Raigarh	OC	SECL	16.03%	0%	83.97%
260	Chhattisgarh	Raigarh	Gare Palma Sector IV/2 & IV/3	Mand-Raigarh	Raigarh	OC	SECL	16.03%	0%	83.97%
261	Chhattisgarh	Raigarh	Bijari	Mand-Raigarh	Raigarh	OC	SECL	16.03%	0%	83.97%
262	Chhattisgarh	Raigarh	Baroud OC	Mand-Raigarh	Raigarh	OC	SECL	16.03%	0%	83.97%
263	Chhattisgarh	Raigarh	Jampali	Mand-Raigarh	Raigarh	OC	SECL	16.03%	0%	83.97%
264	Chhattisgarh	Raigarh	Chhal Co	Mand-Raigarh	Raigarh	OC	SECL	16.03%	0%	83.97%
265	Chhattisgarh	Korba	Manikpur OC	Korba	Korba	OC	SECL	89.61%	10.39%	
266	Chhattisgarh	Korba	Kusmunda OC	Korba	Kusmunda	OC	SECL	89.61%	10.39%	
267	Chhattisgarh	Korba	Gevra	Korba	Gevra	OC	SECL	89.61%	10.39%	

268	Chhattisgarh	Korba	Dipka	Korba	Dipka	OC	SECL	89.61%	10.39%	
269	Chhattisgarh	Korba	Saraipali	Korba	Korba	OC	SECL	89.61%	10.39%	
270	Chhattisgarh	Korba	Rajgamar 4&5	Korba	Korba	UG	SECL	89.61%	10.39%	
271	Chhattisgarh	Korba	Balgi	Korba	Korba	UG	SECL	89.61%	10.39%	
272	Chhattisgarh	Korba	Surakacchar	Korba	Korba	UG	SECL	89.61%	10.39%	
273	Chhattisgarh	Korba	Surakacchar 3&4	Korba	Korba	UG	SECL	89.61%	10.39%	
274	Chhattisgarh	Korba	Singhali	Korba	Korba	UG	SECL	89.61%	10.39%	
275	Chhattisgarh	Korba	Bagdeva	Korba	Korba	UG	SECL	89.61%	10.39%	
276	Chhattisgarh	Korba	Dhelwadih	Korba	Korba	UG	SECL	89.61%	10.39%	
277	Chhattisgarh	Bharatpur	Rani Atari	Chirimiri	Chirimiri	UG	SECL	100%		
278	Chhattisgarh	Bharatpur	Vijay West	Chirimiri	Chirimiri	UG	SECL	100%		
279	Chhattisgarh	Bharatpur	Chirimiri OC/ Anjan Hill	Chirimiri	Chirimiri	OC	SECL	100%		
280	Chhattisgarh	Bharatpur	Bartunga Hill	Chirimiri	Chirimiri	UG	SECL	100%		
281	Chhattisgarh	Bharatpur	Kurasia	Chirimiri	Chirimiri	UG	SECL	100%		
282	Chhattisgarh	Bharatpur	NCPH R6 new	Chirimiri	Chirimiri	UG	SECL	100%		
283	Chhattisgarh	Bharatpur	West Chirimiri Colliery	Chirimiri	Chirimiri	OC	SECL	100%		
284	Chhattisgarh	Koriya	Churcha RO	Sonhat	Baikunthpur	UG	SECL	78.24%	21.76%	0%
285	Chhattisgarh	Koriya	Katkona 1&2	Jhilimili	Baikunthpur	UG	SECL	100%	0%	0%
286	Chhattisgarh	Koriya	Katkona 3&4	Jhilimili	Baikunthpur	UG	SECL	100%	0%	0%
287	Chhattisgarh	Koriya	Jhilimili	Jhilimili	Baikunthpur	UG	SECL	100%	0%	0%
288	Chhattisgarh	Koriya	Pandavpara	Jhilimili	Baikunthpur	UG	SECL	100%	0%	0%
289	Chhattisgarh	Surajpur	Amagaon	Bishrampur	Bisrampur	OC	SECL			
290	Chhattisgarh	Surajpur	Ketki	Bishrampur	Bisrampur	UG	SECL			
291	Chhattisgarh	Surajpur	Gayatri	Bishrampur	Bisrampur	UG	SECL			
292	Chhattisgarh	Surajpur	Rehar	Bishrampur	Bisrampur	UG	SECL			
293	Chhattisgarh	Surajpur	Amera OC	Bishrampur	Bisrampur	OC	SECL			
294	Chhattisgarh	Surajpur	Bisrampur OC	Bishrampur	Bisrampur	OC	SECL			
295	Chhattisgarh	Surajpur	Kumda 7&8	Bishrampur	Bisrampur	UG	SECL			

296	Chhattisgarh	Surajpur	Balrampur	Bishrampur	Bisrampur	UG	SECL			
297	Chhattisgarh	Raipur	Bhatgaon	Bhatgaon	Bhatgaon	UG	SECL			
298	Chhattisgarh	Raipur	Mahan	Bhatgaon	Bhatgaon	OC	SECL			
299	Chhattisgarh	Raipur	Mahamaya	Bhatgaon	Bhatgaon	UG	SECL			
300	Chhattisgarh	Raipur	Shiwani	Bhatgaon	Bhatgaon	UG	SECL			
301	Chhattisgarh	Raipur	Nawapara	Bhatgaon	Bhatgaon	UG	SECL			
302	Chhattisgarh	Raipur	Mahan-II	Bhatgaon	Bhatgaon	OC	SECL			
303	Madhya Pradesh	Anuppur	West JKD	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
304	Madhya Pradesh	Anuppur	Haldibari	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
305	Madhya Pradesh	Anuppur	Kapildhara	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
306	Madhya Pradesh	Anuppur	Beheraband	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
307	Madhya Pradesh	Anuppur	Bijuri	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
308	Madhya Pradesh	Anuppur	Kurja/ Sheetaldhara	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
309	Madhya Pradesh	Anuppur	Rajnagar OC	Sohagpur	Hasdeo	OC	SECL	96.57%	3.43%	0%
310	Madhya Pradesh	Anuppur	Rajnagar R.O.	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
311	Madhya Pradesh	Anuppur	Jhiria	Sohagpur	Hasdeo	UG	SECL	96.57%	3.43%	0%
312	Madhya Pradesh	Anuppur	Amadand	Sohagpur	Jamuna & Kotma	OC	SECL	96.57%	3.43%	0%
313	Madhya Pradesh	Anuppur	Bartarai	Sohagpur	Jamuna & Kotma	UG	SECL	96.57%	3.43%	0%
314	Madhya Pradesh	Anuppur	Meera	Sohagpur	Jamuna & Kotma	UG	SECL	96.57%	3.43%	0%

315	Madhya Pradesh	Anuppur	Bhadra 7/8	Sohagpur	Jamuna & Kotma	UG	SECL	96.57%	3.43%	0%
316	Madhya Pradesh	Anuppur	Jamuna 9&10	Sohagpur	Jamuna & Kotma	UG	SECL	96.57%	3.43%	0%
317	Madhya Pradesh	Anuppur	Jamuna 1&2	Sohagpur	Jamuna & Kotma	UG	SECL	96.57%	3.43%	0%
318	Madhya Pradesh	Narmadapuram	sharda Highwall	Sohagpur	Sohagpur	UG	SECL	96.57%	3.43%	0%
319	Madhya Pradesh	Narmadapuram	Amlai OC	Sohagpur	Sohagpur	OC	SECL	96.57%	3.43%	0%
320	Madhya Pradesh	Narmadapuram	Dhanpuri OC	Sohagpur	Sohagpur	OC	SECL	96.57%	3.43%	0%
321	Madhya Pradesh	Narmadapuram	Bangwar	Sohagpur	Sohagpur	UG	SECL	96.57%	3.43%	0%
322	Madhya Pradesh	Narmadapuram	Rajendra	Sohagpur	Sohagpur	UG	SECL	96.57%	3.43%	0%
323	Madhya Pradesh	Narmadapuram	Khairaha	Sohagpur	Sohagpur	UG	SECL	96.57%	3.43%	0%
324	Madhya Pradesh	Narmadapuram	Damini	Sohagpur	Sohagpur	UG	SECL	96.57%	3.43%	0%
325	Madhya Pradesh	Shahdol	Bicharpur	NA	NA	UG	Ultra Tech Cement Ltd			
326	Madhya Pradesh	Umaria	Pali	Johilla	Johilla	UG	SECL	100%	100%	100%
327	Madhya Pradesh	Umaria	Nowrozabad(W)	Johilla	Johilla	UG	SECL	100%	100%	100%
328	Madhya Pradesh	Umaria	Pinoura	Johilla	Johilla	UG	SECL	100%	100%	100%
329	Madhya Pradesh	Umaria	Vindhya	Johilla	Johilla	UG	SECL	100%	100%	100%

330	Madhya Pradesh	Umaria	Kanchan Opencast	Johilla	Johilla	OC	SECL	100%	100%	100%
331	Madhya Pradesh	Umaria	Umaria	Johilla	Johilla	UG	SECL	100%	100%	100%
332	Madhya Pradesh	Umaria	Piparia	Johilla	Johilla	UG	SECL	100%	100%	100%
333	Madhya Pradesh	Chhindwara	Mandla North	NA	NA	UG	Jaiprakash Associates Ltd.			
334	Madhya Pradesh	Chhindwara	Jamunia	PKT	Pench	UG	WCL	78.80%	21.20%	0%
335	Madhya Pradesh	Chhindwara	Neheriya	PKT	Pench	UG	WCL	78.80%	21.20%	0%
336	Madhya Pradesh	Chhindwara	Urdhan OC	PKT	Pench	OC	WCL	78.80%	21.20%	0%
337	Madhya Pradesh	Chhindwara	Mathani	PKT	Pench	UG	WCL	78.80%	21.20%	0%
338	Madhya Pradesh	Chhindwara	Shivpuri OC	PKT	Pench	OC	WCL	78.80%	21.20%	0%
339	Madhya Pradesh	Chhindwara	Chhinda OC	PKT	Pench	OC	WCL	78.80%	21.20%	0%
340	Madhya Pradesh	Chhindwara	Vishnupuri-I	PKT	Pench	UG	WCL	78.80%	21.20%	0%
341	Madhya Pradesh	Chhindwara	Vishnupuri-II	PKT	Pench	UG	WCL	78.80%	21.20%	0%
342	Madhya Pradesh	Chhindwara	New Sethia OC	PKT	Pench	OC	WCL	78.80%	21.20%	0%
343	Madhya Pradesh	Chhindwara	Ganpati	PKT	Pench	UG	WCL	78.80%	21.20%	0%
344	Madhya Pradesh	Chhindwara	Mahadevpuri	PKT	Pench	UG	WCL	78.80%	21.20%	0%

345	Madhya Pradesh	Chhindwara	Barkui OC	PKT	Pench	OC	WCL	78.80%	21.20%	0%
346	Madhya Pradesh	Chhindwara	Mohan (Mohan UG & Mohan OC)	PKT	Kanhan	Mixed	WCL	78.80%	21.20%	0%
347	Madhya Pradesh	Chhindwara	Ghorawari Colliery	PKT	MVK	OC	WCL	78.80%	21.20%	0%
348	Madhya Pradesh	Chhindwara	Ghorawari No. 1 (Jharna UG & 16/17 OC)	PKT	Kanhan	Mixed	WCL	78.80%	21.20%	0%
349	Madhya Pradesh	Chhindwara	Nandan- II	PKT	Kanhan	UG	WCL	78.80%	21.20%	0%
350	Madhya Pradesh	Chhindwara	Tandsi	PKT	Kanhan	UG	WCL	78.80%	21.20%	0%
351	Madhya Pradesh	Betul	Tawa-II	PKT	Pathakhera	UG	WCL	78.80%	21.20%	0%
352	Madhya Pradesh	Betul	Tawa-I	PKT	Pathakhera	UG	WCL	78.80%	21.20%	0%
353	Madhya Pradesh	Betul	Shobhapur	PKT	Pathakhera	UG	WCL	78.80%	21.20%	0%
354	Madhya Pradesh	Betul	Sarni	PKT	Pathakhera	UG	WCL	78.80%	21.20%	0%
355	Madhya Pradesh	Betul	Chhatarpur-I	PKT	Pathakhera	UG	WCL	78.80%	21.20%	0%
356	Madhya Pradesh	Betul	Chhatarpur-II	PKT	Pathakhera	UG	WCL	78.80%	21.20%	0%
357	Madhya Pradesh	Singrauli	Amelia North	NA	NA	OC	Jaiprakash Power Ventures Ltd.			
358	Madhya Pradesh	Singrauli	Blok B	Singrauli	Blok B	OC	NCL	79.57%	20.31%	0.12%

359	Madhya Pradesh	Singrauli	Amlohri	Singrauli	Amlohri	OC	NCL	79.57%	20.31%	0.12%
360	Madhya Pradesh	Singrauli	Nigahi	Singrauli	Nigahi	OC	NCL	79.57%	20.31%	0.12%
361	Madhya Pradesh	Singrauli	Jayant	Singrauli	Jayant	OC	NCL	79.57%	20.31%	0.12%
362	Madhya Pradesh	Singrauli	Jhingurdah	Singrauli	Jhingurdah	OC	NCL	79.57%	20.31%	0.12%
363	Madhya Pradesh	Singrauli	Dudhichua	Singrauli	Dudhichua	OC	NCL	79.57%	20.31%	0.12%
364	Madhya Pradesh	Singrauli	Moher & Moher Amlohri Extn	NA	NA	OC	Power Finance Corporation (sasan UMPP)			
365	Uttar Pradesh	Sonbhadra	Khadia	Singrauli	Khadia	OC	NCL	79.57%	20.31%	0.12%
366	Uttar Pradesh	Bahraich	Kakri	Singrauli	Kakri	OC	NCL	79.57%	20.31%	0.12%
367	Uttar Pradesh	Sonbhadra	Bina	Singrauli	Bina	OC	NCL	79.57%	20.31%	0.12%
368	Uttar Pradesh	Sonbhadra	Krishnashila	Singrauli	Krishnashila	OC	NCL	79.57%	20.31%	0.12%
369	Maharashtra	Nagpur	Belgaon	NA	NA	UG	Sunflag Iron & Steel Ltd			
370	Maharashtra	Chandrapur	Majra	NA	NA	Mixed	Jaypee Cement Corp Ltd			
371	Maharashtra	Chandrapur	Baranj I, Baranj II, Baranj III, Baranj IV, Manora Deep & Kiloni	NA	NA	OC	Karnataka Power Corp Ltd			
372	Maharashtra	Yavatmal	Marki Mangli-I	NA	NA	OC	Topworth Urja and Metals Ltd			
373	Maharashtra	Yavatmal	Marki Mangli-III	NA	NA	OC	B.S. Ispat Ltd			

374	Maharashtra	Nagpur	Saoner-II	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
375	Maharashtra	Nagpur	Saoner-III	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
376	Maharashtra	Nagpur	Waghoda	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
377	Maharashtra	Nagpur	Saoner-I	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
378	Maharashtra	Nagpur	Adasa	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
379	Maharashtra	Nagpur	Patansaongi	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
380	Maharashtra	Nagpur	Pipla	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
381	Maharashtra	Nagpur	AB Incline	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
382	Maharashtra	Nagpur	Silewera	Kamptee	Nagpur	UG	WCL	88.41%	11.07%	0.52%
383	Maharashtra	Nagpur	Singhri OC	Kamptee	Nagpur	OC	WCL	88.41%	11.07%	0.52%
384	Maharashtra	Nagpur	Bhanegaon OC	Kamptee	Nagpur	OC	WCL	88.41%	11.07%	0.52%
385	Maharashtra	Nagpur	Gondegaon OC	Kamptee	Nagpur	OC	WCL	88.41%	11.07%	0.52%
386	Maharashtra	Nagpur	Inder OC	Kamptee	Nagpur	OC	WCL	88.41%	11.07%	0.52%
387	Maharashtra	Nagpur	Kamptee OC	Kamptee	Nagpur	OC	WCL	88.41%	11.07%	0.52%
388	Maharashtra	Nagpur	Makardhokra-III	Umrer	Umrer	OC	WCL	100%	0%	0%
389	Maharashtra	Nagpur	Makardhokra-I	Umrer	Umrer	OC	WCL	100%	0%	0%
390	Maharashtra	Nagpur	Umrer OCM	Umrer	Umrer	OC	WCL	100%	0%	0%
391	Maharashtra	Nagpur	Murpar	Umrer	Umrer	UG	WCL	100%	0%	0%
392	Maharashtra	Nagpur	Gokul OCM	Bander	Umrer	OC	WCL	66.05%	33.95%	0.00%
393	Maharashtra	Chandrapur	Yekona II OC	Wardha Valley	Majri	OC	WCL	98.95%	1.05%	0%
394	Maharashtra	Yavatmal	Rajur/ Bhandewada Inc	Wardha Valley	Wani North	UG	WCL	98.95%	1.05%	0%
395	Maharashtra	Yavatmal	Kumbarkhani	Wardha Valley	Wani North	UG	WCL	98.95%	1.05%	0%
396	Maharashtra	Yavatmal	Ghonsa OC	Wardha Valley	Wani North	OC	WCL	98.95%	1.05%	0%
397	Maharashtra	Chandrapur	Newmajri UG to OC	Wardha Valley	Majri	OC	WCL	98.95%	1.05%	0%
398	Maharashtra	Chandrapur	New Majri OC II (A) Expansion	Wardha Valley	Majri	OC	WCL	98.95%	1.05%	0%
399	Maharashtra	Chandrapur	Navin Kunada OC	Wardha Valley	Majri	OC	WCL	98.95%	1.05%	0%

400	Maharashtra	Yavatmal	Kolarpimpri OCM	Wardha Valley	Wani North	OC	WCL	98.95%	1.05%	0%
401	Maharashtra	Chandrapur	Juna Kunada OC	Wardha Valley	Majri	OC	WCL	98.95%	1.05%	0%
402	Maharashtra	Chandrapur	Dhorwasa OC	Wardha Valley	Majri	OC	WCL	98.95%	1.05%	0%
403	Maharashtra	Chandrapur	Telwasa OC	Wardha Valley	Majri	OC	WCL	98.95%	1.05%	0%
404	Maharashtra	Yavatmal	Pimpalgaon OC	Wardha Valley	Wani North	OC	WCL	98.95%	1.05%	0%
405	Maharashtra	Yavatmal	Junad OC	Wardha Valley	Wani North	OC	WCL	98.95%	1.05%	0%
406	Maharashtra	Yavatmal	Ukni OC	Wardha Valley	Wani North	OC	WCL	98.95%	1.05%	0%
407	Maharashtra	Yavatmal	Niljai OC	Wardha Valley	Wani	OC	WCL	98.95%	1.05%	0%
408	Maharashtra	Yavatmal	Naigaon-Bellora OC	Wardha Valley	Wani	OC	WCL	98.95%	1.05%	0%
409	Maharashtra	Yavatmal	Mugoli OC	Wardha Valley	Wani	OC	WCL	98.95%	1.05%	0%
410	Maharashtra	Yavatmal	Kolgaon OCM	Wardha Valley	Wani	OC	WCL	98.95%	1.05%	0%
411	Maharashtra	Yavatmal	Penganga OCM	Wardha Valley	Wani	OC	WCL	98.95%	1.05%	0%
412	Maharashtra	Chandrapur	Bhatadi OC	Wardha Valley	Chandrapur	OC	WCL	98.95%	1.05%	0%
413	Maharashtra	Chandrapur	Padmapur OCM	Wardha Valley	Chandrapur	OC	WCL	98.95%	1.05%	0%
414	Maharashtra	Chandrapur	Durgapur OCM	Wardha Valley	Chandrapur	OC	WCL	98.95%	1.05%	0%
415	Maharashtra	Chandrapur	D. Rayatwari	Wardha Valley	Chandrapur	UG	WCL	98.95%	1.05%	0%
416	Maharashtra	Chandrapur	Chanda Rayatwari	Wardha Valley	Chandrapur	UG	WCL	98.95%	1.05%	0%
417	Maharashtra	Chandrapur	Mahakali	Wardha Valley	Chandrapur	UG	WCL	98.95%	1.05%	0%
418	Maharashtra	Chandrapur	Hindustan Lalpeth OC	Wardha Valley	Chandrapur	OC	WCL	98.95%	1.05%	0%
419	Maharashtra	Chandrapur	HLC No.1	Wardha Valley	Chandrapur	UG	WCL	98.95%	1.05%	0%
420	Maharashtra	Chandrapur	Nandgaon	Wardha Valley	Chandrapur	UG	WCL	98.95%	1.05%	0%

421	Maharashtra	Chandrapur	Manna Incline	Wardha Valley	Chandrapur	UG	WCL	98.95%	1.05%	0%
422	Maharashtra	Chandrapur	Ballarpur	Wardha Valley	Ballarpur	UG	WCL	98.95%	1.05%	0%
423	Maharashtra	Chandrapur	Ballarpur OCM	Wardha Valley	Ballarpur	OC	WCL	98.95%	1.05%	0%
424	Maharashtra	Chandrapur	Sasti	Wardha Valley	Ballarpur	UG	WCL	98.95%	1.05%	0%
425	Maharashtra	Chandrapur	Sasti OC	Wardha Valley	Ballarpur	OC	WCL	98.95%	1.05%	0%
426	Maharashtra	Chandrapur	Gouri Expn OCM	Wardha Valley	Ballarpur	OC	WCL	98.95%	1.05%	0%
427	Maharashtra	Chandrapur	Pauni OC	Wardha Valley	Ballarpur	OC	WCL	98.95%	1.05%	0%
428	Maharashtra	Chandrapur	Pauni Expn. OC	Wardha Valley	Ballarpur	OC	WCL	98.95%	1.05%	0%
429	Maharashtra	Chandrapur	Gouri Deep OC	Wardha Valley	Ballarpur	OC	WCL	98.95%	1.05%	0%
430	Telengana	Karimnagar	Tedicherla-I	NA	NA	OC	Telengana State General Power Corporation Ltd			
431	Telengana	Komaram Bheem	Khairigura OC			OC	SCCL			
432	Telengana	Komaram Bheem	Bellampalli OC II			OC	SCCL			
433	Telengana	Mancherial	Kasipet-2			UG	SCCL			
434	Telengana	Mancherial	Kasipet-1			UG	SCCL			
435	Telengana	Mancherial	Kalyankhani			OC	SCCL			
436	Telengana	Mancherial	Shanthikhani			UG	SCCL			
437	Telengana	Mancherial	KK1			UG	SCCL			
438	Telengana	Mancherial	KK5			UG	SCCL			
439	Telengana	Mancherial	Ravindrakhani-1A Incline			UG	SCCL			

440	Telengana	Mancherial	Ramkrishnapur OC			OC	SCCL			
441	Telengana	Mancherial	RK-5			UG	SCCL			
442	Telengana	Mancherial	RK-6			UG	SCCL			
443	Telengana	Mancherial	RK-7			UG	SCCL			
444	Telengana	Mancherial	RK-8			UG	SCCL			
445	Telengana	Mancherial	RKNT			UG	SCCL			
446	Telengana	Mancherial	SRP 1			UG	SCCL			
447	Telengana	Mancherial	SRP 3 3A			UG	SCCL			
448	Telengana	Mancherial	Srirampur OC			OC	SCCL			
449	Telengana	Mancherial	IK OC			OC	SCCL			
450	Telengana	Mancherial	IK 1A Incl.			UG	SCCL			
451	Telengana	Peddapalli	RG-I OC Medipalli OCP			OC	SCCL			
452	Telengana	Peddapalli	Godavarikhani-1&3			UG	SCCL			
453	Telengana	Peddapalli	Godavarikhani-2&2A			UG	SCCL			
454	Telengana	Peddapalli	Godavarikhani-7 LEP			UG	SCCL			
455	Telengana	Peddapalli	Godavarikhani-11			UG	SCCL			
456	Telengana	Peddapalli	RGOC-3 & PH2			OC	SCCL			
457	Telengana	Peddapalli	Vakilpalli			UG	SCCL			
458	Telengana	Peddapalli	Ramagundam OC-I Exp. Ph-II			OC	SCCL			
459	Telengana	Peddapalli	Adriyala Shaft project			UG	SCCL			
460	Telengana	Peddapalli	Ramagundam OC-II Extn.			OC	SCCL			
461	Telengana	Jayashankar Bhoopalpalli	Kakatiyakhani-1 & 1A Incline			UG	SCCL			

462	Telengana	Jayashankar Bhoopalpalli	KTKOC-2			OC	SCCL			
463	Telengana	Jayashankar Bhoopalpalli	Kakatiyakhani-6 Incline			UG	SCCL			
464	Telengana	Jayashankar Bhoopalpalli	Kakatiyakhani-5 Incline			UG	SCCL			
465	Telengana	Jayashankar Bhoopalpalli	Kakatiyakhani-8 & 8A			UG	SCCL			
466	Telengana	Bhadradri Kothagudem	Manuguru OC			OC	SCCL			
467	Telengana	Bhadradri Kothagudem	Prakasham Khani OC			OC	SCCL			
468	Telengana	Bhadradri Kothagudem	Kondapuram			UG	SCCL			
469	Telengana	Bhadradri Kothagudem	Koyagudem OC II			OC	SCCL			
470	Telengana	Bhadradri Kothagudem	Jawaharkhani OC 5			OC	SCCL			
471	Telengana	Bhadradri Kothagudem	Padmavathikhani-5 Incline			UG	SCCL			
472	Telengana	Bhadradri Kothagudem	Venkateshkhani-7 Incline			UG	SCCL			
473	Telengana	Bhadradri Kothagudem	Goutamkhani			OC	SCCL			
474	Telengana	Bhadradri Kothagudem	Kistaram OC			OC	SCCL			
475	Telengana	Bhadradri Kothagudem	JVR OC 1&2			OC	SCCL			

Source: PwC analyses of energy map of India by NITI Aayog & ISRO

A.2. Coal fields

Table 78: List of coal field with details

Coal field Name	Coal Type	Depth (m)	Reserves (Million Tonne)				Reserves (%)
			Proved	Indicated	Inferred	Total	Proved Reserve %
Talcher	Non Coking	0-300	19771.42	10284.52	2481.48	32537.42	85.59%
Talcher	Non Coking	300-600	3103.47	12315.7	1054.28	16473.45	13.43%
Talcher	Non Coking	600-1200	225.94	1359.11	469.21	2054.26	0.98%
IB_Valley	Non Coking	0-300	10083.24	4880.44	141	15104.68	90.08%
IB_Valley	Non Coking	300-600	1110.44	4140.39	4168.93	9419.76	9.92%
IB_Valley	Non Coking	600-1200	0	303.41	2.69	306.1	0.00%
Raniganj	Medium Coking	0-300	422.89	8.87	0	431.76	2.83%
Raniganj	Medium Coking	300-600	121.89	8.3	0	130.19	0.82%
Raniganj	Medium Coking	600-1200	274.87	0	0	274.87	1.84%
Raniganj	Semi Coking	0-300	97.15	14.19	0	111.34	0.65%
Raniganj	Semi Coking	300-600	109.51	153.23	23.48	286.22	0.73%
Raniganj	Semi Coking	600-1200	32.79	305.07	144.75	482.61	0.22%
Raniganj	Non Coking	0-300	11131.62	1765.92	297.35	13194.89	74.51%
Raniganj	Non Coking	300-600	2442.56	3636.93	2098.32	8177.81	16.35%
Raniganj	Non Coking	600-1200	306.16	1851.06	1494.87	3652.09	2.05%

Coal field Name	Coal Type	Depth (m)	Reserves (Million Tonne)				Reserves (%)
			Proved	Indicated	Inferred	Total	Proved Reserve %
Rajmahal & Birbhum	Non Coking	0-300	2978.84	8350.15	809.75	12138.74	92.76%
Rajmahal & Birbhum	Non Coking	300-600	232.34	7384.57	1727.49	9344.4	7.24%
Rajmahal & Birbhum	Non Coking	600-1200	0	1227.84	179.15	1406.99	0.00%
Saharjhuri	No data	No data	No data	No data	No data	No data	
Giridih	No data	No data	No data	No data	No data	No data	
Ramgarh	Medium Coking	0-300	562.69	37.55	0	600.24	74.42%
Ramgarh	Medium Coking	300-600	14.35	246.78	0	261.13	1.90%
Ramgarh	Semi Coking	0-300	171.94	95.33	0.55	267.82	22.74%
Ramgarh	Semi Coking	300-600	0	336.22	52.9	389.12	0.00%
Ramgarh	Non Coking	0-300	7.13	26.2	4.6	37.93	0.94%
Jharia Coalfiels	Prime Coking	0-600	4039.41	4.01	0	4043.42	26.69%
Jharia Coalfiels	Prime Coking	600-1200	574.94	694.7	0	1269.64	3.80%
Jharia Coalfiels	Medium Coking	0-600	4064.18	2.82	0	4067	26.85%
Jharia Coalfiels	Medium Coking	600-1200	296.3	1800.7	0	2097	1.96%
Jharia Coalfiels	Non Coking	0-600	5657.14	444.86	0	6102	37.38%
Jharia Coalfiels	Non Coking	600-1200	496	1355	0	1851	3.28%

Coal field Name	Coal Type	Depth (m)	Reserves (Million Tonne)				Reserves (%)
			Proved	Indicated	Inferred	Total	Proved Reserve %
East Bokaro	Medium Coking	0-300	2618.33	1258.81	18.71	3895.85	77.33%
East Bokaro	Medium Coking	300-600	407.44	1188.33	58.53	1654.3	12.03%
East Bokaro	Medium Coking	600-1200	255.93	1394.07	786.08	2436.08	7.56%
East Bokaro	Non Coking	0-300	95.17	56.81	0	151.98	2.81%
East Bokaro	Non Coking	300-600	8.9	5.69	0	14.59	0.26%
West Bokaro	Medium Coking	0-300	2990.73	1116.32	28.66	4135.71	79.51%
West Bokaro	Medium Coking	300-600	496.14	178.36	5	679.5	13.19%
West Bokaro	Non Coking	0-300	268.57	9.37	0	277.94	7.14%
West Bokaro	Non Coking	300-600	5.81	4.66	0	10.47	0.15%
South Karanpura	Medium Coking	300-600	0	248.04	32.83	280.87	0.00%
South Karanpura	Medium Coking	600-1200	0	265.36	263.4	528.76	0.00%
South Karanpura	Non Coking	0-300	2831.92	514.3	276.36	3622.58	86.35%
South Karanpura	Non Coking	300-600	445.46	725.09	644.03	1814.58	13.58%
South Karanpura	Non Coking	600-1200	2.25	134.69	252.51	389.45	0.07%
North Karanpura	Medium Coking	0-300	485.08	1163.22	0	1648.3	4.71%

Coal field Name	Coal Type	Depth (m)	Reserves (Million Tonne)				Reserves (%)
			Proved	Indicated	Inferred	Total	Proved Reserve %
North Karanpura	Medium Coking	300-600	23.59	1635.92	413.43	2072.94	0.23%
North Karanpura	Non Coking	0-300	8606.67	2244.43	722.03	11573.13	83.48%
North Karanpura	Non Coking	300-600	1103.56	1125.8	729.5	2958.86	10.70%
North Karanpura	Non Coking	600-1200	90.74	0	0	90.74	0.88%
Auranga	Non Coking	0-300	352.05	1241.22	43.07	1636.34	100.00%
Auranga	Non Coking	300-600	0	867.01	423.07	1290.08	0.00%
Auranga	Non Coking	600-1200	0	33.42	37.27	70.69	0.00%
Hutar	Non Coking	0-300	190.79	14.22	32.48	237.49	100.00%
Hutar	Non Coking	300-600	0	12.33	0	12.33	0.00%
Daltonganj	Non Coking	0-300	83.86	60.1	0	143.96	100.00%
Mand-Raigarh	Non Coking	300-600	1365.8	6651.19	525.99	8542.98	16.03%
Mand-Raigarh	Non Coking	600-1200	0	610.88	0	610.88	0.00%
Mand-Raigarh	Non Coking	0-300	7153.29	12194.87	1125.41	20473.57	83.97%
Tatapani- Ramkola	Non Coking	0-300	50.43	1161.68	24.85	1236.96	100.00%
Tatapani- Ramkola	Non Coking	300-600	0	1361.24	184.83	1546.07	0.00%

Coal field Name	Coal Type	Depth (m)	Reserves (Million Tonne)				Reserves (%)
			Proved	Indicated	Inferred	Total	Proved Reserve %
Tatapani- Ramkola	Non Coking	600-1200	0	303.36	0	303.36	0.00%
Bisrampur	Non Coking	0-300	1141.94	506.91	1.82	1650.67	100.00%
Bisrampur	Non Coking	0-300	0	164.82	0	164.82	0.00%
Lakhanpur	Non Coking	0-300	455.88	3.35	0	459.23	100.00%
Hasdo-Arand	Non Coking	0-300	2021.84	3213.44	220.15	5455.43	99.49%
Hasdo-Arand	Non Coking	300-600	10.44	59.98	2.97	73.39	0.51%
Korba	Non Coking	0-300	5266.34	3491.5	99.91	8857.75	89.61%
Korba	Non Coking	300-600	610.92	2292.2	68.11	2971.23	10.39%
Sendurgarh	Non Coking	0-300	152.89	126.32	0	279.21	100.00%
Chirimiri	Non Coking	0-300	320.33	10.83	31	362.16	100.00%
Sonhat	Semi Coking	0-300	70.77	16.45	0	87.22	26.89%
Sonhat	Semi Coking	300-600	0	82.8	0	82.8	0.00%
Sonhat	Non Coking	0-300	135.13	903.21	0	1038.34	51.35%
Sonhat	Non Coking	300-600	57.25	829.84	1.89	888.98	21.76%
Sonhat	Non Coking	600-1200	0	568.85	0	568.85	0.00%
Jhilimili	Non Coking	0-300	228.2	38.9	0	267.1	100.00%
Singrauli	Non Coking	0-300	6295.39	2624.9	1219.69	10139.98	79.57%

Coal field Name	Coal Type	Depth (m)	Reserves (Million Tonne)				Reserves (%)
			Proved	Indicated	Inferred	Total	Proved Reserve %
Singrauli	Non Coking	300-600	1607.25	3113.34	794.03	5514.62	20.31%
Singrauli	Non Coking	600-1200	9.54	140.07	72.68	222.29	0.12%
Sohagpur	Medium Coking	0-300	184.57	211.38	2.01	397.96	10.00%
Sohagpur	Medium Coking	300-600	62.09	866.78	90.54	1019.41	3.36%
Sohagpur	Medium Coking	600-1200	0	81.94	21.7	103.64	0.00%
Sohagpur	Non Coking	0-300	1597.93	2908.87	186.98	4693.78	86.57%
Sohagpur	Non Coking	300-600	1.27	1651.86	18.19	1671.32	0.07%
Sohagpur	Non Coking	600-1200	0	33.61	0	33.61	0.00%
Johilla	Non Coking	0-300	185.08	104.09	32.83	322	100.00%
Korar	No data	No data	No data	No data	No data	No data	
PKT	Medium Coking	0-300	67.54	263.11	16.41	347.06	4.57%
PKT	Medium Coking	300-600	40.29	136.9	142.17	319.36	2.73%
PKT	Non Coking	0-300	1096.28	203.72	138.67	1438.67	74.23%
PKT	Non Coking	300-600	272.77	366.61	434.94	1074.32	18.47%
PKT	Non Coking	600-1200	0	0	0.86	0.86	0.00%
Umria	Non Coking	0-300	177.7	3.59	0	181.29	100.00%
Umrer	Non Coking	0-300	308.41	0	65.53	373.94	100.00%
Umrer	Non Coking	300-600	0	0	83.22	83.22	0.00%

Coal field Name	Coal Type	Depth (m)	Reserves (Million Tonne)				Reserves (%)
			Proved	Indicated	Inferred	Total	Proved Reserve %
Umrer	Non Coking	600-1200	0	0	11.95	11.95	0.00%
Wardha Valley	Non Coking	0-300	3717.31	745.28	298.17	4760.76	98.95%
Wardha Valley	Non Coking	300-600	39.47	770.9	1156.2	1966.57	1.05%
Wardha Valley	Non Coking	600-1200	0	13.37	26.99	40.36	0.00%
Bander	Non Coking	0-300	397.69	298.36	0	696.05	66.05%
Bander	Non Coking	300-600	204.37	177.06	0	381.43	33.95%
Bander	Non Coking	600-1200	0	16.76	0	16.76	0.00%
Kamptee & Katol	Non Coking	0-300	1353.25	511.89	41.76	1906.9	88.41%
Kamptee & Katol	Non Coking	300-600	169.4	603.79	234.13	1007.32	11.07%
Kamptee & Katol	Non Coking	600-1200	8.03	13.69	138.72	160.44	0.52%

Source: PwC analyses of energy map of India by NITI Aayog & ISRO

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