# CAVERN STORAGE UNDER THE SEA BED - RENEWABLE ELECTRICITY STORAGE IN EUROPE 2025

3/5/2014

project outline

Concept of pumped storage hydroelectric plant under the sea bed to store renewable energy generated by offshore, coastal onshore wind farms and solar parks with locations in Belgium and the Netherlands

## PROJECT OUTLINE

### INITIATIVE

The EC DG Energy has shown high interest in this concept and made the suggestion to set up a consortium to apply for a PCI (project of common interest) to access EU funding. The key partners that need to be identified are one or more TSOs which are showing interest in the project and are willing to support it. The main objectives of the PCI is to receive

- faster planning permission
- financial support (including research funding, grants and project funding via EIB)

The project promoter should be a TSO with partners

The project solution we are proposing will tick all the required criteria

- Infrastructure improvement
- 2 member states are involved
- Positive impact on electrical storage and transmission networks
- Increases System flexibility,
- Based on renewable energy to improve security of supply
- CO2 reduction
- Priority of electricity corridors: Northern Sea due to Belgium and the Netherlands location

Key partners we have identified who would be interested in participating in such a common European project include:

- Hochtief Solution AG
- Voith (Hydro) GmbH
- Herrenknecht AG
- Pöyry Europe.

# CHALLENGES FOR RENEWABLE ELECTRICITY STORAGE

The challenge of renewable energy is in the near future will be to ensure security of supply. Wind is always a volatile fuel. Statistically distributed over the year, there is sufficient wind power available, but the challenge remains to adjust the power generated from renewable energy to the geographic and temporal demand curves. The North Sea is the location of most of the large-scale wind generation sites whilst the large centres of consumption of electricity are partly located away on the continent of Europe.

There are therefore significant requirements for electricity storage and transport and interconnect infrastructures.

The challenge to transport electricity from the northern wind production sites to the key electricity consumer sites in the southern industry locations and the storage of renewable wind energy in the north have not been solved to date.  A number of network studies have noted that the intermitted energy generation from off-shore wind power threatens the stability of the existing power grid. There are basically only two approaches:

1 Massive expansion of power grids in North-South direction

2 Construction of electricity storage at the site of volatile production near off-shore wind farms.

Both approaches are complementary and can be optimized. If the wind power is stored in the north at times of high generation but low demand and released at times of highs demands, then the requirement for transmission network infrastructure is reduced and the planned expansion and additional network might be reduced accordingly.

An additional challenge for the construction of large-scale transmission network capacity, however, will be the slow approval process and political resistance in many European countries along the planned routes.

# POSSIBLE SOLUTION SCENARIO

Our proposed solution is a cavern storage system 400-600m below the seabed equipped with underwater pump turbines. Seawater is introduced via an environmentally friendly shaft and drives turbines. This pump storage facility would generate 2GW power which could be fully discharged within six hours. The total storage capacity will be 13 GWh. Under optimal conditions two charge/discharge cycles are possible every 24 hours. The pumped storage facility is charged during periods of low electricity demand and can be discharged immediately at periods when the demand outstrips the available capacity.

A balancing or smoothing mechanism is created for on-shore and/or off-shore wind farms by selecting a suitable connection point of the cavern system with the transmission grid close to the connection of offshore wind farms with the transmission network. This storage facility is powered solely by renewable energy, i.e. emptying and refilled of the cavern by wind energy.

Our initial studies have showed a suitable location for a pumped storage hydro-electric (PSH) plant near Ostend/Bruges on the coast of Belgium connecting Belgian and Dutch off-shore wind farms:

- Belwind Blingh Bank & C-Power Thorontenbank (Belgium) and

- Princess Amalia (Netherlands)


**FIGURE 1 GENERAL OVERVIEW OF LOACTION OF PSW AND WIND FARMS OFF THE COAST OF BELGIUM**

# INNOVATIVE LOCATION ADVANTAGES

The innovative idea for this specific location is to connect two off-shore wind farms in two different European neighbour countries via a sea cable to allow load balancing between Dutch & Belgian consumers.
The existing infrastructure of the existing nuclear plant at Doel (3 GW power), which is planned to be decommissioned in the year 2025, could be utilized by the PSH because it will become available at about the time the PSH starts operating. Antwerp and Rotterdam are key power consumers and both centres could be reached via the existing electrical infrastructure of the nuclear power station
Finally, the pumped storage facility could be connected to a third European country, the UK, via the planned undersea cable NEMO which will become available in 2017.

# PUMPED-STORAGE HYDROELECTRICS PLANT DESCRIPTION

The pumped-storage hydroelectric plant uses the hydrostatic water pressure at sea levels off North and Baltic Sea, at a depth of 400-600 m. The plant could be fed from excess electricity generated by off-shore or, depending on the grid connection point and where available on-shore wind farms. A typical plant will have the following structure:

- air, inspection and access pit coast side (initial vertical cavity)
- storage tunnel or gallery below sea level in a solid geological layer (cretaceous, marl or chalk)
- intake, outlet, air, inspection and access shaft in the sea near off-shore wind farms (vertical cavity at the outer and of the cavern)
- cavern for electric generating equipment (turbine) below the intake and outlet pits (this will also serve as the turning basin for the tunnel drilling equipment during cavern construction)
- one or more horizontal cavern for water flooding in during generation or pumped empty during charging operations
- discharge closure devices
- hydroelectric generating set with pump turbine, generator und electrical connection plant

The storage will be provided by separate caverns (tunnels) dug in a solid geological layer deep under the sea bed. The (typically) twin tunnels will be drilled at a depth of 400 to 600 m. The tunnels will have a diameter of 12 to 15 m. The tunnel drilling machine will be taken through the inspection and access shaft coast side. The tunnel drilling machine will be used to dig the tunnels over a length of approx. 50 km ending up in the area of off- shore wind farms. The turning cavern for the drilling equipment will be built at the end of the storage tunnels sea side. This cavern will later house the electricity generating equipment, the room for the electrical connection plant and the stilling basin below the intake, outlet, air, inspection and access shaft.

The intake, outlet, air, inspection and access shaft sea side will be built in parallel with drilling the coast side shaft using a pressurised caisson for deep-sea work.

After the completion the PSH plant, sea water will be allowed into storage tunnels through the inlet shaft and passes through the electricity generating turbines, filling the storage tunnels. The pressurised air is discharged through the coast side air shaft. At times of excess wind capacity, the turbines work in reverse and pump out the storage tunnels again taking in air from the coast side air shafts.

As an example, the supply shaft on someone of the German island (in the North Sea off Germany) is used for air in and outlet. Furthermore, a factory workshop is built on top of the coast side shaft which contains a crane for supply of equipment to the turbine hall. The coast side shaft is separated from the storage tunnels by an air-tight access hatch.

The storage tunnels off the island will also be used as HV cable routes for connection of the off-shore wind farm. It will only be necessary to lay undersea cables from the island to the shore.

The PSH facility will have a minimum capacity of 2.2 MW with a storage volume of 12m m3. This is comparable to pump storage facilities built in mountain areas (e.g. Goldisthal, Germany). The capacity can generally be increased by adding additional storage tunnels.

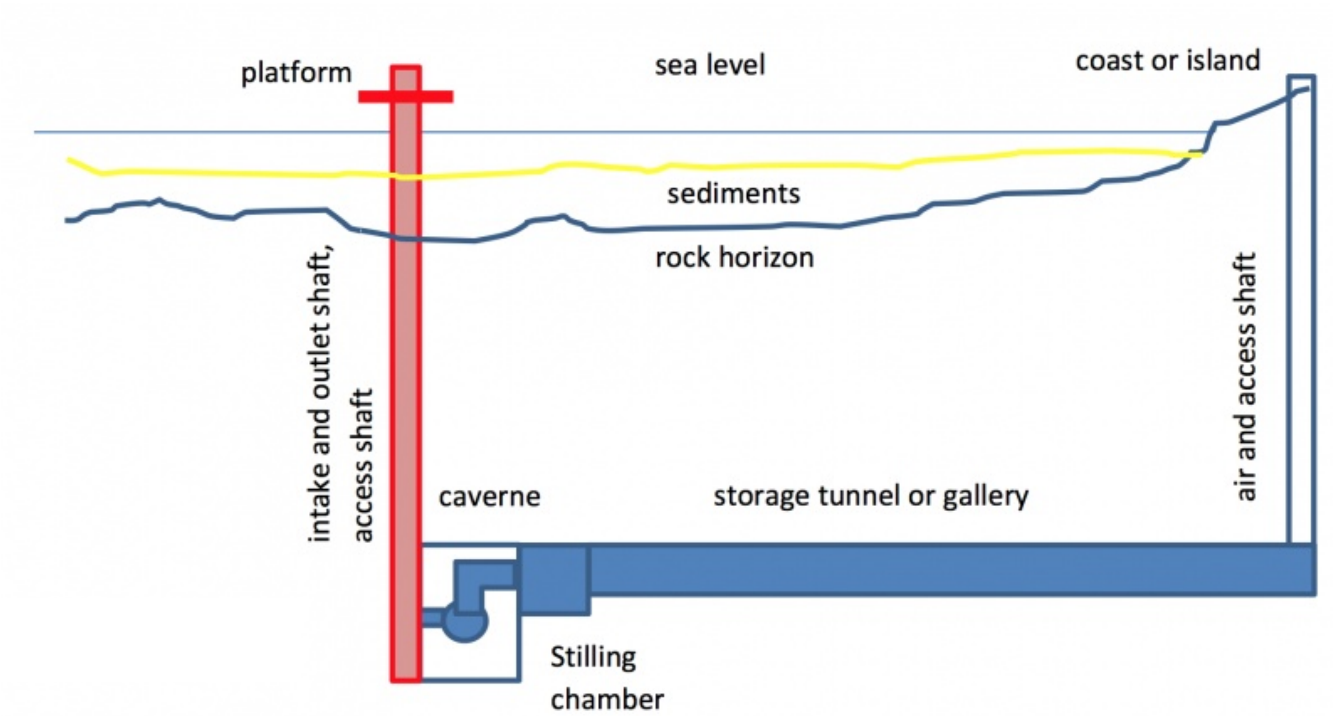


**FIGURE 2 LONGITUDINAL SECTION SHALLOW WATER TYPE**

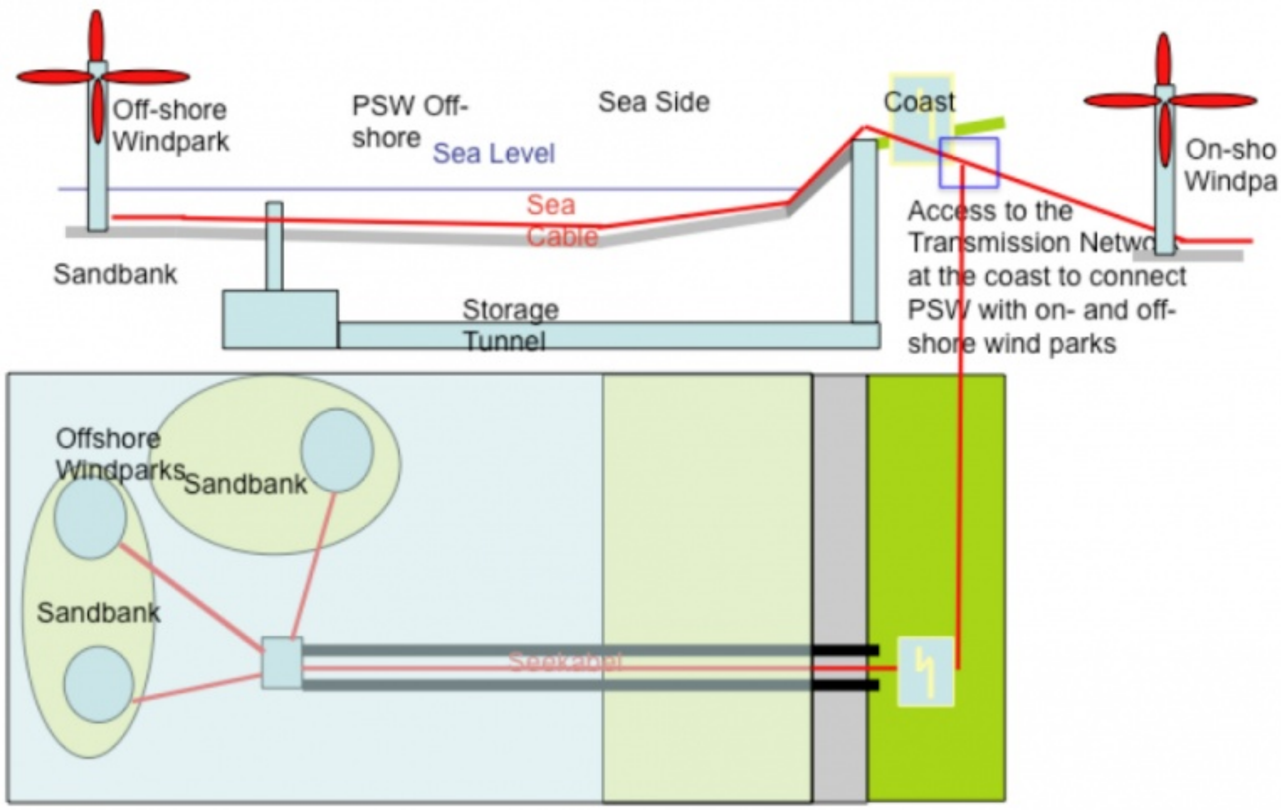


FIGURE 3 BASIC PRINCIPLE AND OVERALL VIEW

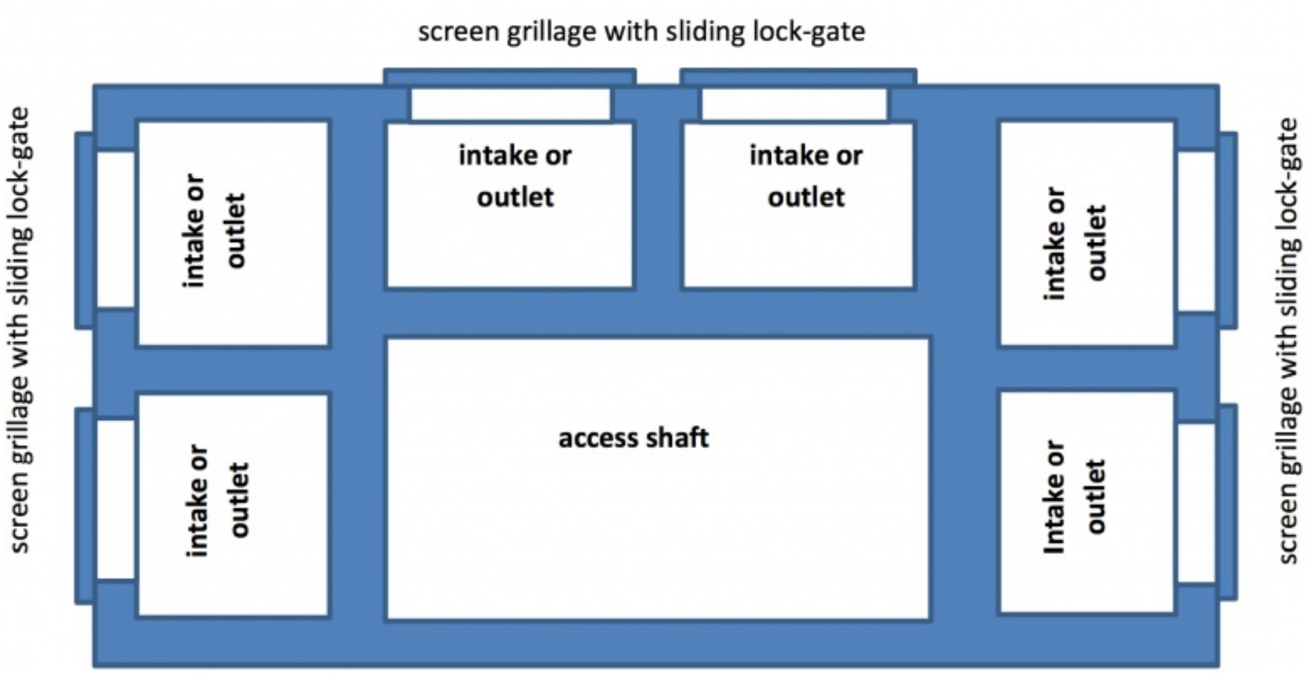


FIGURE 4 CROSS-SECTION AIR AND ACCESS SAHFT OFFSHORE

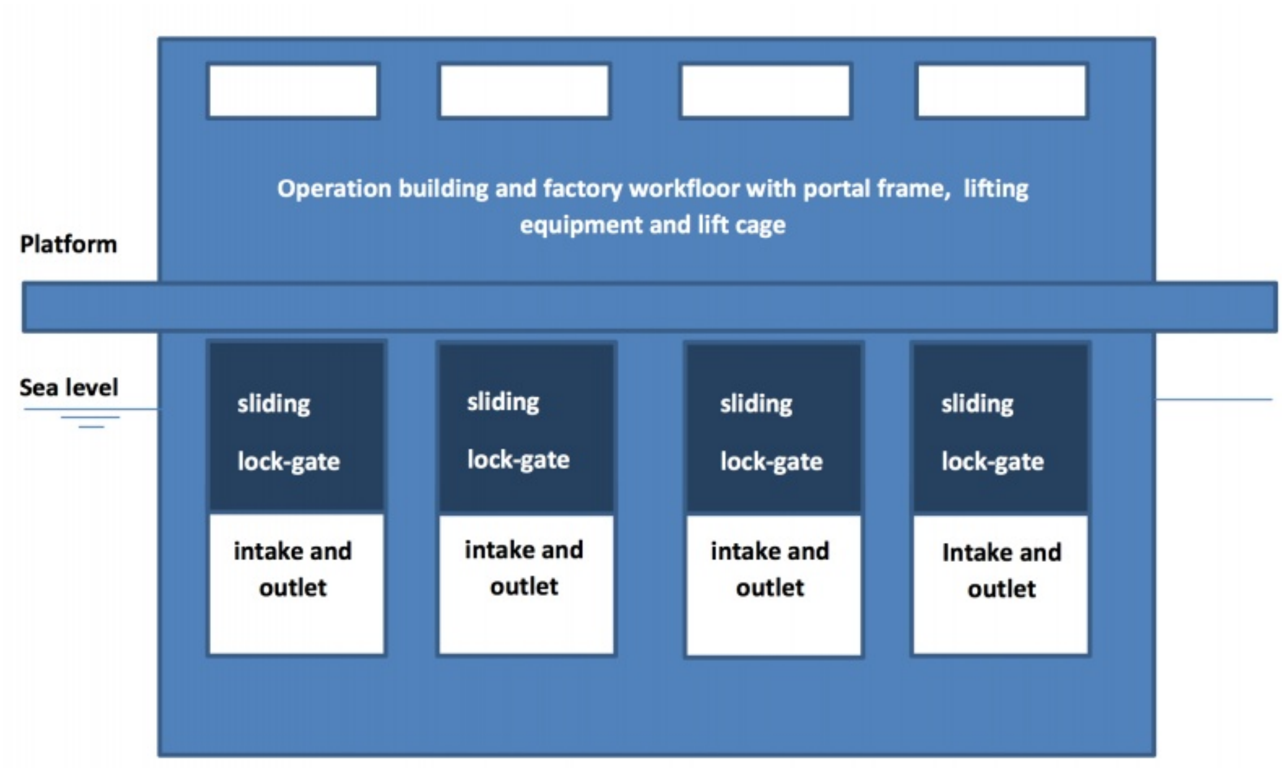


FIGURE 5 VIEW AIR SHAFT AND ACCESS SHAFT (INTAKE AND PLATFORM)

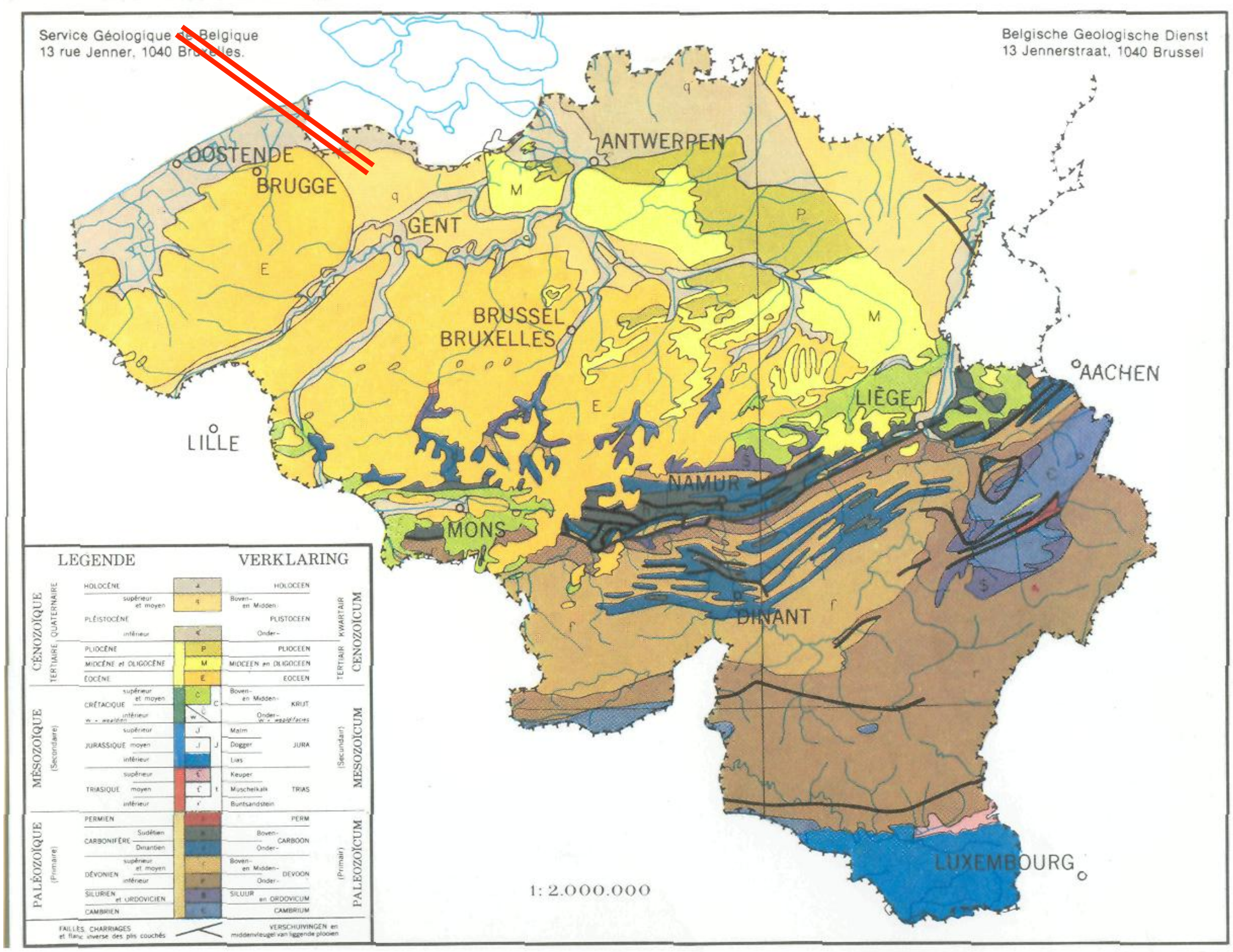


**FIGURE 6 GEOLOCICAL MAP OF BELGIUM**

## CONSTRUCTION PROCESS

The construction process consists of the following key phases:

- construction of the land-side access shaft
- construction of the sea-side access and ventilation shaft
- drilling of twin tunnels with a length of 50 km using tunnel boring machines similar to those used for the construction of the Euro-Tunnel and similar projects. The twin tunnels could be drilled either in parallel or sequentially, depending on available time and budget.

Construction of the land-side access and sea-side ventilation & access shafts will take three years. Drilling of the tunnels can be completed in two years. The construction of the engine hall and installation of turbines will take another two years. Thus the overall construction period is estimated to take 6-7 years. Together with a 2-3 year planning and permitting phase, the overall project delivery time frame would be 8-10 years.

## CONSTRUCTION COST ESTIMATES

Usually are carried in tunnels at € 20,000 per meter of tunnel. 15 to 20% can be calculated for the expansion and technical equipment. With this assumption, the price would be reduced for the storage tunnel around 6,000 to 8,000 € to 12,000 € per tunnel meter per meter of tunnel. The construction costs are as follows, a first rough estimate as follows:

| **PSH Plant Cost Estimates** | | | | | |
|---|---|---|---|---|---|
| **No.** | **Description** | **Amount** | **Unit** | **Unit Cost (€)** | **Mio €** |
| 1 | Sea-side Access Shaft | 500 | m | 10,000 € | 5.00 |
| 2 | Storage Cavern | 100,000 | m | 12,000 € | 1,200.00 |
| 3 | Machine Cavern | 280,000 | m³ | 150 € | 42.00 |
| 4 | Transformer Cavern | 53,000 | m³ | 150 € | 7.95 |
| 5 | Pressure Shafts (500m each) | 1,000 | m | 75,000 € | 75.00 |
| 6 | Closure Mechanism | 6 | per turbine | 7,000,000 € | 42.00 |
| 7 | Pump Turbine 350MW | 6 | per turbine | 35,000,000 € | 210.00 |
| 8 | Other Machinery | 6 | per turbine | 7,000,000 € | 42.00 |
| 9 | Generator | 6 | per turbine | 40,000,000 € | 240.00 |
| 10 | Other Electrical Installations | 6 | per turbine | 20,000,000 € | 120.00 |
| 11 | Control Systems | 1 | | 15,000,000 € | 15.00 |
| 12 | Engineering Design | 1 | | 1,500,000 € | 10.00 |
| | | | | **Total Costs** | **2,009** |

**FIGURE 1 COST ESTIMATE**