*“The electricity is like a shark.*

*If it stops moving, it will die.”*

**S4P2**

**(Semi Solid State Storage Power Plant)**

**Installed capacity - 2 000 kWpeakInstalled elevators power - 115 kWDaily capacity - stored - 1 236.27 kWh Equivalent PV facility area - 2.6 haDaily capacity - produced - 1 055.53 kWhEfficiency - 85.4 %Annual capacity - 389.27 MWhTotal cost - $ 5 900 000Cost per installed watt - 2.95 $/W**

**Introduction**

The main problem of the renewable energy is its dependence on sunrise and sunset and the whims of nature. To exists, the electricity must be in continuous movement between the producer and the consumer. To balance the production and the consumption, electricity must be stored. The only way is to turn it into another kind of energy such as chemical or mechanical.

In the first case, the electricity is stored in a giant battery, but it has a limited lifespan and cycles of charge and discharge. The efficiency is up to 90% and has a cost between $280 and $360 per kWh. The lifespan is of maximum 20 years with the current technology. However, the question about the cost of battery recycling after these 20 years has no answer yet.

In the second case, the PSH (Pumped Storage Hydro) power plants are the most used ones. They use the kinetic power from falling water, which has been raised to an upper dam by a pump in order to be stored. The additional losses are from evaporation and absorption of the water. Another disadvantage is the limited geographical locations – the needs of a high mountain and a lot of water. About 95% of the world’s energy-storage capacity comes in the form of this technology and about 75% of these power plants have been built [in only 10 countries](https://qz.com/1295901/why-energy-storage-is-key-to-a-global-climate-breakthrough/). The efficiency of PHS is between 70% and 80% and has a cost between $200 and $260 per kWh. The lifespan is about 100 years or more.

In last years, there are some experiments with Solid State Storage (SSS) power plants. In some examples, the water is replaced with concrete weights. The concrete is about 2.3 times heavier than the water and in that way the high of raise is 2.3 time smaller. The efficiency of SSS is up to 85% and has a cost of about $150 per kWh. The lifespan is about 30 years or more.

The proposed installation for Masdar city is a storage power plant with use of sand. On the one hand, the sand at rest is a solid-state object, that weights is 1.8 time more than the water. On the other hand, when the sand is falling, it has a high viscous liquid behavior. Therefore, the current project’s name is Semi Solid State Storage Power Plant or in short **S4P2**. Thus, this technology is suitable for countries that do not have an excess of water, but have a lot of sand.

The principle is the same as the one of PSH. The sand is stored in underground storage and then is raised to the overground silo by three chain-bucket elevators driven by electric motors. Then the sand falls down and rotates a turbine to produce electricity.

**Form & Site**

The form of the installation is a cube stepped on his vertex on the wheel and supported by a tripod. The composition between a circle (movement, instability) and a square (rest, stability) gives a sense of dynamics or frozen kinematics.

That giant sculpture is placed on the west side of the proposed site. The terrain is modified in such a way that it forms an amphitheater 4.5 m under the ground level. It has pedestrian access to the east side under the city road by a tunnel and a ramp.

**Construction**

The skeleton of the installation is spatial steel construction. The tripod structure supports the cubic frame (24 x 24 x 24 m). The steel sand silo is stretched on this frame. The silo’s volume is 11’000 m3 or 19’800 tons of sand. The height to the top of the installation is 45 meters from ground level.

**Silo**

The form of the silo is a conical cube. The construction is spatial steel structure with double skin steel plates. There is a telescopic sand inlet (**1**) placed into the silo. The point of it being with various height is that the falling sand flow would transform the maximum potencial power to kinetic power.

**Turbine & Alternator**

The sand flow has a rate of 3.84 m3/s (**2**), with various high of falling. The special design of the turbine buckets serves to transform the maximum of the kinetic power into a torque (**3**) as well as to reduce the incoming flow velocity to zero on the bucket’s bottom. This way the sand is collect in rest after falling with minimal losses and it serve to produce an additional static torque (**4**) similar to the ancient “knight’s wheel”. The main wheel torque is a result of the sum of these two torques (**5**).

The construction of the turbine is a spatial steel structure looking like a coreless wheel, placed between two cylindrical concrete shells. Along the turbine wheel edges are mounted small train wheels and on the inner surface of the shells – rails. This way the turbine looks like a giant bearing. The turbine buckets is placed in the center of the outer surface of the wheel. On both of the inner and the outer surface of the wheel there are five rolls of permanent natural magnets – two of them are on the outer side and three on the inner. The turbine buckets and the permanent magnets form the alternator’s rotor. The rotor’s angular speed is 12 rpm (**6**). Five rows of coils are placed in axial direction on the inner and the outer concrete shells in the role of a stator. Into the shells there is integrated a cooling system. The rotor and the stator form frameless (coreless, brushless) alternator for direct drive without any gears and other mechanical parts to generate a maximum power (**7**). The silo’s volume and flow rate define the total time of electricity production (**8**).

Between the two shells, on both sides of the wheel there are seamless acrylic glassing. Through the glass, people can see the movement of the rotor. This is the only way people can understand that the sculpture is also a machine.

**Bucket elevators**

There are three chain-bucket elevators placed in the construction tripod. The operative height of two of them is 40 m. The third has biggest operative height of 61 m. The economy obtained of these two different heights is about 18% of summary efficiency. The installed elevators power is 245 kW (**10**). The elevators have different speed and time of filling the silo (**9**).

**Cost**

1. Turbine & Alternator wheel - $ 2 600 000

2. Chain bucket elevators (3 pieces)

 - Operative height 61 m – 1 piece - $ 100 000

 - Operative height 40 m – 2 pieces - $ 160 000

3. Underground storage

 - Formwork - 4 750 m2 - $ 171 000

 - Concrete - 2 300 m3 - $ 248 000

 - Steel (reinforced concrete) - 570 t - $ 534 000

4. Silo

 - Spatial steel construction - 180 t - $ 340 000

 - Steel plates - 270 t - $ 510 000

 - Steel tripod - 3 x 65 t - $ 375 000

5. Excavation - 15 000 m3 - $ 300 000

6. Sand - 20 000 t - $ 0

7. Other - 10%

Total - $ 5 900 000

Cost per installed watt - 2.95 $/W

**Calculations**

(**1**) Sand inlet has a cone of consumption with an angle of 120º at the vertex cause of slope of repose of the sand (30º).**(6)**

**(7)**

 **T** – Torque. **R** – Angular speed.

**(10)**

**C** – Capacity of the elevator. **H** - Elevator discharge height. **K** - Summary coefficient. It can be find in the manufacturer tables.



\* **1.8 [t/m3]** - sand density.

\*\* **35** - number of filled buckets.