



DAY 1 SESSION 4 16.20
TOPIC 11 – Pumped Storage Schemes and Hydro Power Development

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Geomembranes in pumped storage schemes

G. Vaschetti, Vanja Verdel
Carpi Tech – Switzerland

Presented by Allan Jackson – Commercial Director Carpi Group

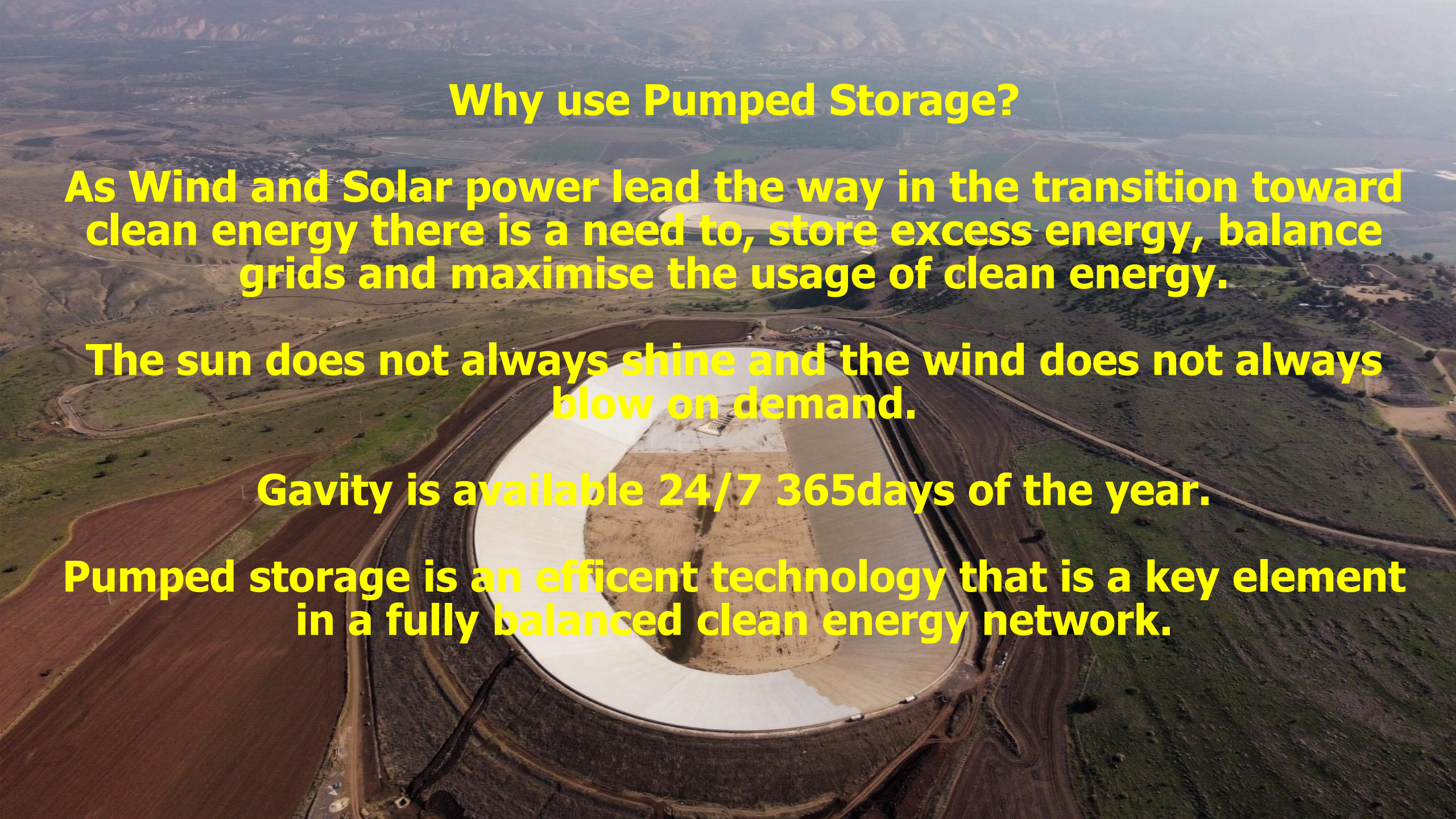
Why use Pumped Storage?

As Wind and Solar power lead the way in the transition toward clean energy there is a need to, store excess energy, balance grids and maximise the usage of clean energy.

The sun does not always shine and the wind does not always blow on demand.

Gravity is available 24/7 365days of the year.

Pumped storage is an efficient technology that is a key element in a fully balanced clean energy network.



Why use Geomembranes in Pumped Storage Projects?

Speed of Construction allowing early commissioning.

Quality control from factory to finished installation.

Low Carbon footprint relative to alternatives.

Long Service life, upto 100yrs

Ability to cope with settlement and seismic loads.

Excellent resistance to UV exposure and extreme climates

General considerations for Pump Storage Projects

Geomembranes in PSS New Construction

- To line the upper and/or lower reservoir
- To line other structures in the scheme (hydro tunnels, shafts, canals)

Geomembranes in PSS Rehabilitation

- To restore watertightness of structures in the scheme (dams, reservoirs, hydro tunnels, shafts, canals)
- To line leaking areas, leaking joints, cracks

PSS Requirements

- Watertightness needed to preserve water volume and critical to avoid potential dam or embankment stability issues
- Maintenance period should be minimized, to not affect the production of electricity, thus durable liners are required

Geomembrane Assets

- Allow steeper embankment faces, maximise void space.
- Good performance with settlement and deformation and in earthquakes
- Quick and simple repairs – reduce downtime

Geomembrane system, design considerations

- 💧 Many reservoirs need to be lined with a geomembrane, to conserve water
- 💧 Amount of energy stored is proportional to water head and water volume.
- 💧 Huge quantities of water flow in and out of the reservoirs, at high velocity, many times a week, or once or more a day, creating interesting geomembrane design challenges
- 💧 Geomembranes need to be anchored against water forces generated during filling and emptying reservoirs, and wind forces acting when reservoirs are empty
- 💧 Geomembranes need to be durable, resist settlement and UV exposure.

Geomembrane system design considerations

- Design should consider geomembrane tensile properties, flexibility, elongation and resistance to puncture (to adapt to irregular subgrade), forces transmitted to anchor lines, connections to concrete structures, subsidence and differential settlements
- Geomembrane formulation and thickness, for long service life
- Exposed option preferable, to allow detailed and reliable quality control, inspection during operation, and repairs if needed and even underwater
- Face anchorage to resist rapid water flow during fill/empty cycles, and to resist wind forces when empty
- Perimeter seals designed to resist subsidence and differential settlements

Carpi experience in pumped storage (20 projects)

Name of project	Element	Year
Pinnapuram	Upper and lower reservoirs	2023
Abdelmoumen	Upper and lower reservoirs	2023
Kokhav	Upper and lower reservoirs	2023
Revin	Joint Les Marquisades upper reservoir	2020
Calheta	Pico da Urze upper reservoir	2019
Gilboa	Joints	2018-2019
La Coche	Intake area upper reservoir	2018
Gilboa	Joints	2017
Helms	Pressure tunnel	2017
Gilboa	Vertical wall	2017

Name of project	Element	Year
Panama	18 Reservoirs	2014-2014
Reisseck II	Grosser Mühldorfersee dam – upper reservoir	2013
Dlouhé Stráně	Joints upper reservoir	2012
Eastwood	Shaver Lake dam – lower reservoir	2010-2012
Obervermuntwerk II	Silvretta dams – upper reservoir	2010-2011
Waldeck I	3 dams – upper reservoir	2008
Kadamparai	Dam – upper reservoir	2005
Lake Hodges	Olivenhain dam – upper reservoir	2003
Hohenwarte II	Dam – upper reservoir	2000-2001
Vedello	Scais dam	1992-1995

Pico da Urze – New upper reservoir of Calheta III PSS

- Portugal – Madeira Island
- Combined wind generation and hydropower generation
- Upper reservoir formed by excavation and the Pico da Urze dam



Primary anchorage: longitudinal trenches filled with concrete at crest, on benches, at toe and centre of the invert, also serving as traffic paths



Complementary anchorages: vertical trenches with stainless steel battens and stainless steel profiles fastened to the dam



Perimeter seals

Mechanical and watertight - designed to accept differential settlement



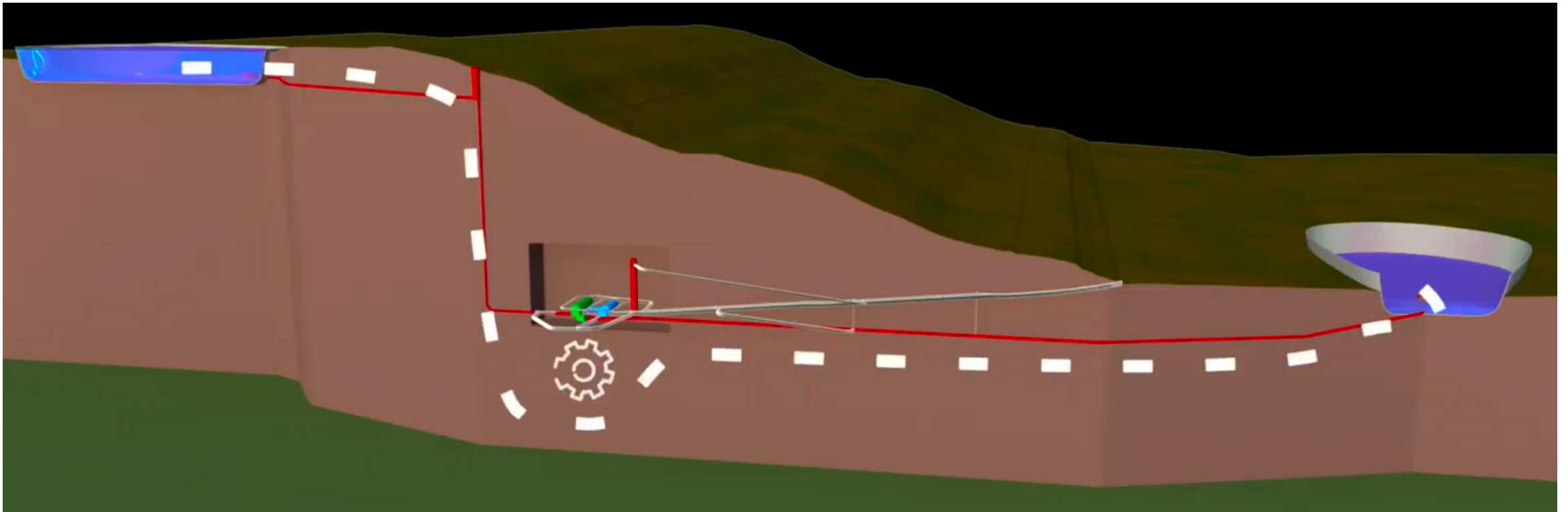
Pico da Urze

- Contract schedule: 104 days for installation, including bad weather
- Completed in 99 days, including more bad weather than expected
- Lined surface 82,400 m²
- Reservoir impounded in January 2020 is performing well



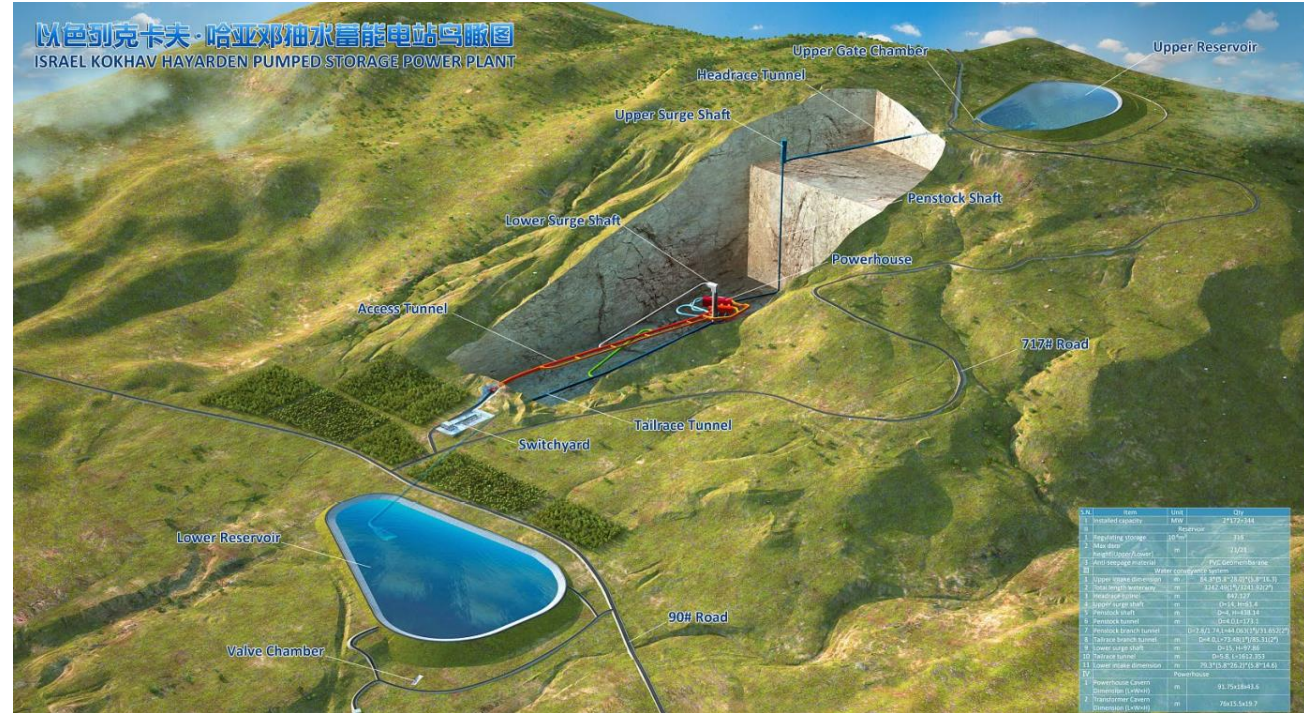
Kokhav Hayarden PSS, Israel

- Upper and lower reservoirs with elevation difference of 450 m, and a capacity of 3 Mm³ each
- Underground water ways and underground power plant



Kokhav Hayarden PSS Upper and lower reservoirs

- Waterproofing of upper and lower reservoirs; total surface 433,000 m²
- Upper reservoir: partially formed by embankment, partially excavated, slopes 3.5H:1V, water fluctuation 22 m
- Lower reservoir: embankment, slopes 3H:1V, water fluctuation 22 m



Subgrade

💧 Upper reservoir

Compacted earthfill and excavation



💧 Lower reservoir

Compacted earthfill



Face anchorage

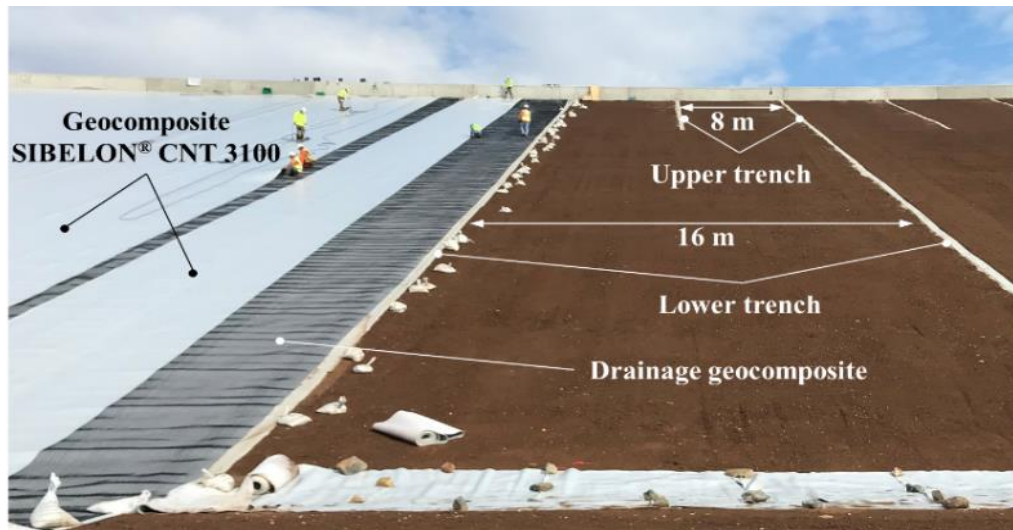
Designed for worst case scenarios, with full and empty reservoirs

- 💧 Design wind velocity: 150 km/h for upper reservoir and 130 km/h for lower reservoir
- 💧 Anchorage on slopes: geomembrane anchor strips embedded in trenches and then ballasted. Trench spacing based on the suction effect of the wind: 8 m to 16 m spacing
- 💧 Anchorage on base: ballasting action of water, because reservoir is never fully emptied



Face anchorage

- **SIBELON® CNT 3100** waterproofing geocomposite (2 mm thick PVC geomembrane bonded to a 500 g/m² polypropylene geotextile)
- Anchored by heat-seaming it to the strips of **SIBELON®** protruding from the trenches - 333 trenches in upper reservoir, 334 in lower reservoir
- Adjacent geocomposite sheets watertight joined by heat-seaming



Kokhav Hayarden PSS

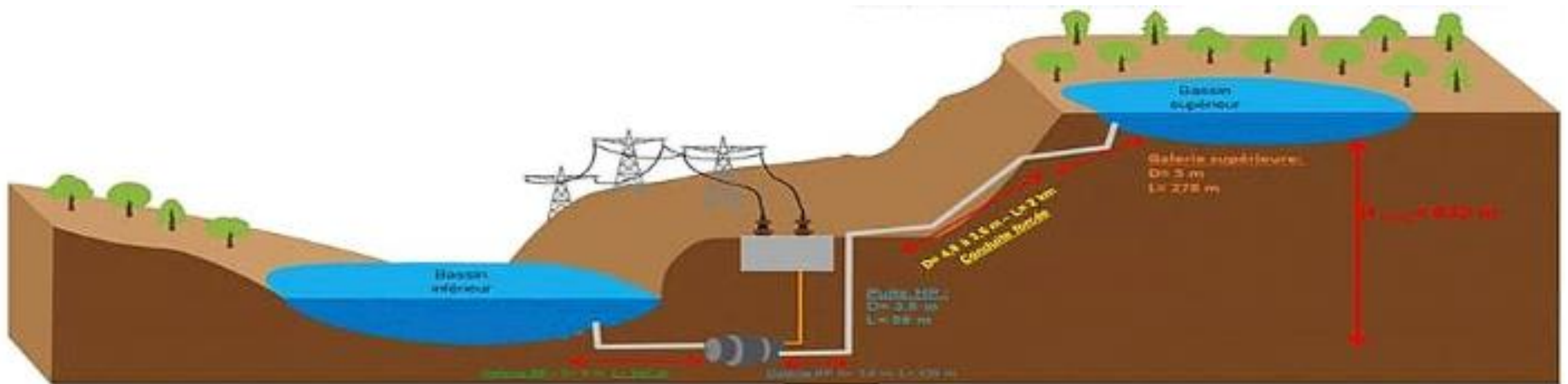
- 💧 Installation commenced July 2020
- 💧 Completed December 2022

- 💧 Impounding started January 2023



Abdelmoumen PSS, Morocco

- To compensate for the fluctuating power output from wind farms
- Two reservoirs with elevation difference of 500 m, connected with a 3 km long waterway
- Water storage capacity 1.3 Mm³, which can be switched up to 20 times a day



Abdelmoumen PSS

Upper and lower reservoirs

- 💧 Total lined surface 195,500 m²
- 💧 Both reservoirs formed by compacted granular material embankments, slope 2H:1V, water fluctuation 20 m
- 💧 Waterproofing liner: **SIBELON® CNT 4400 L**, (3 mm thick PVC geomembrane bonded to a 500 g/m² polypropylene geotextile)
- 💧 Design wind velocity 90 km/h, for both reservoirs, with FoS > 2
- 💧 Anchorage on base same as slopes, because reservoir can be completely emptied

Face anchorage

- Anchor strips placed within reservoir slopes during construction of the embankment



- Waterproofing geocomposite sheets were heat-seamed to anchor strips



Geomembrane face



💧 EFFECT OF WIND NEAR CREST



Lower reservoir fill & intake structure

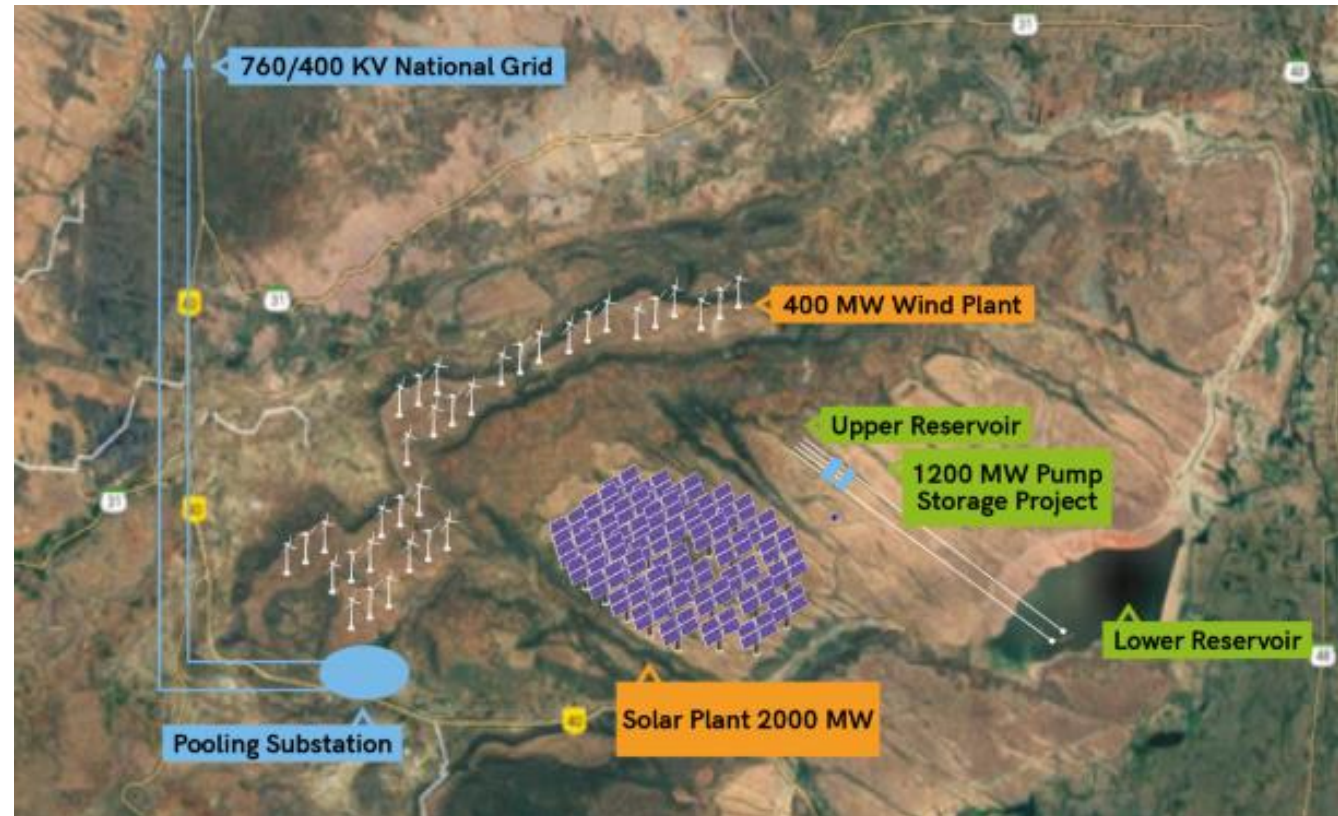


💧 Abdelmoumen lower reservoir near completion



Pinnapuram PSS, India

- Renewable energy from solar and wind
- Upper reservoir: formed by a 9.6 km long rockfill dam
- Lower reservoir: three rockfill dams connecting existing natural slopes



Applications in rehabilitation of PSS

- In rehabilitation geomembranes are used to restore watertightness
- Have been applied to the upstream face of dams and reservoir embankments, to seeping areas, to failing joints and cracks, and to deteriorated pressure tunnels
- Installation can be carried out underwater





THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS