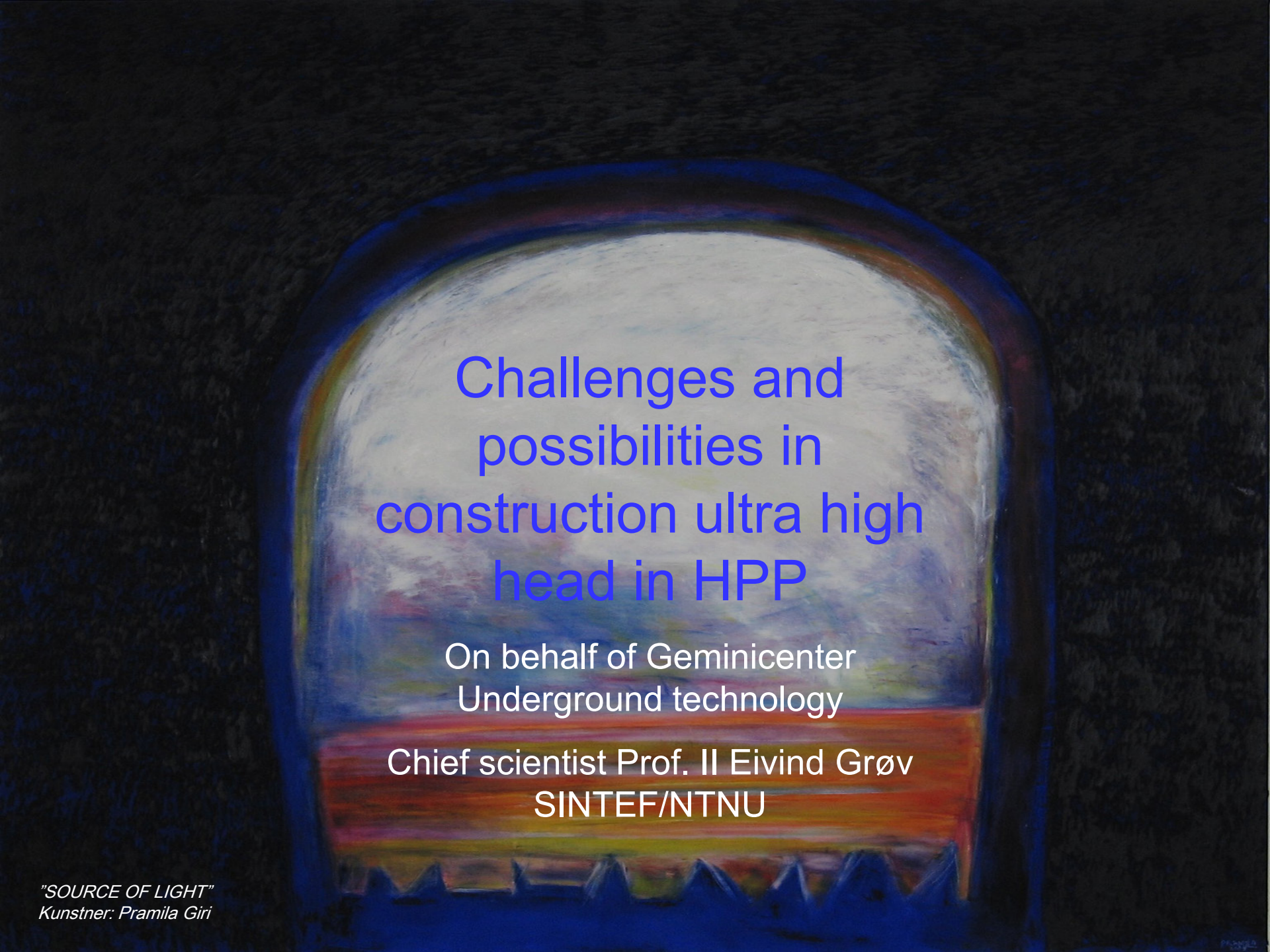


Challenges and possibilities in construction ultra high head in HPP

On behalf of Geminicenter Underground technology

Chief scientist Prof. II Eivind Grøv
SINTEF/NTNU

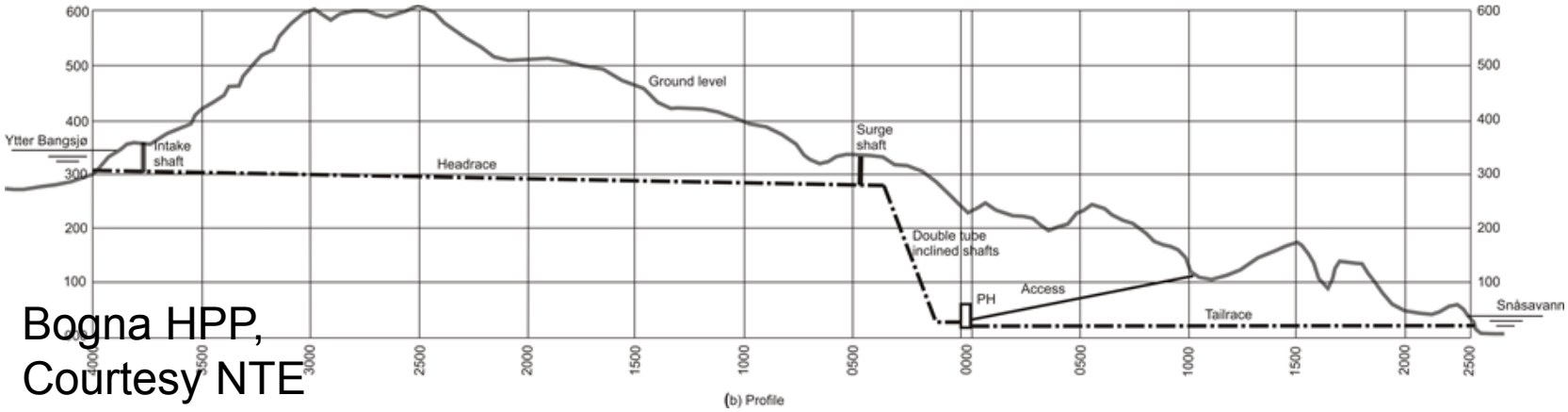
"SOURCE OF LIGHT"
Kunstner: Pramila Giri

Pumped HPP using ultra high head in unlined tunnels

What characterizes the typical Norwegian HPP scheme?

Large upper reservoirs at high elevations, long tunnels (head race up to 50km), small cross-sections (15-30m2), high heads (1000m +), continuous production, low water velocity (appr. 1m/sek)

Concept driven by topography, consumers location and demands ++



Bogna HPP, Courtesy NTE

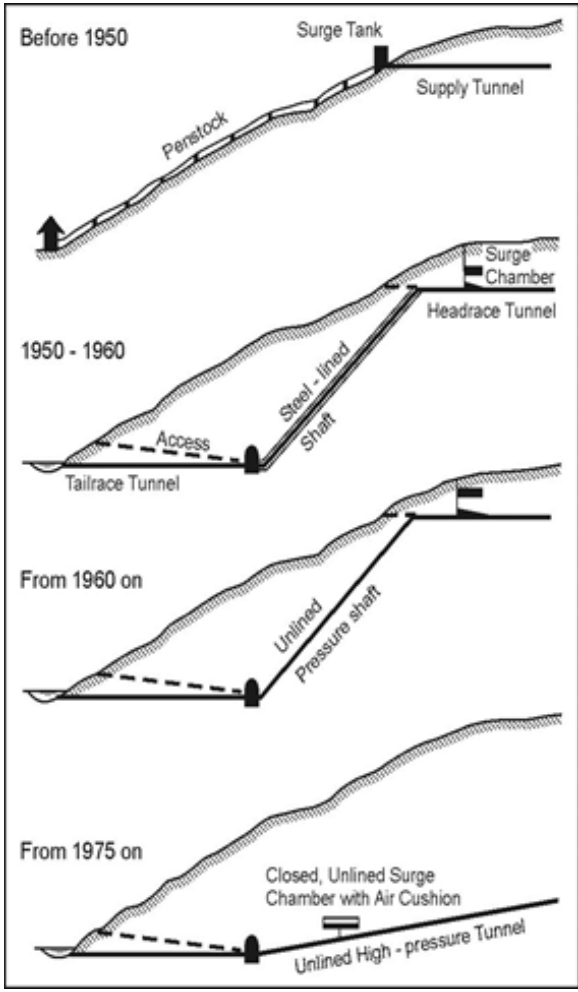
Pumped HPP using ultra high head in unlined tunnels

The development of Norwegian high head HPP concepts:

Note the following:

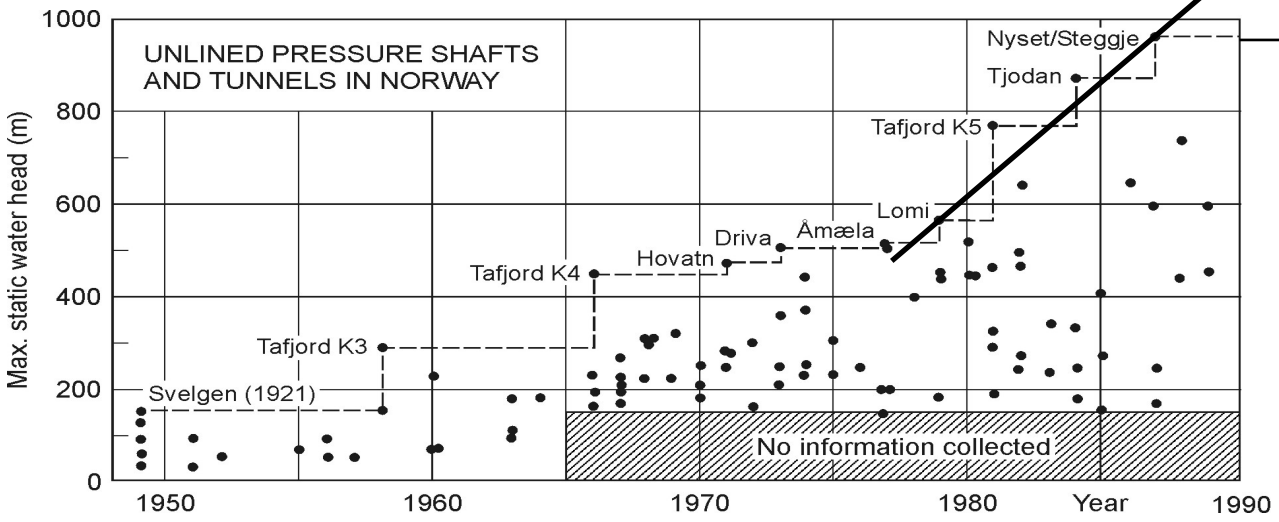
- High heads
- Unlined tunnelling
- Taking advantage of the capacity of the rock mass as construction material
- In-situ stress situation is crucial
- Tunnelling is a robust and viable construction method and element

These aspects materialized the concept



Pumped HPP using ultra high head in unlined tunnels

New Tyin used the existing concessions and reservoir regulations
Reached above 1000 m head
World record in unlined head race tunnels



Tyin 2007

Between the 80'ies and today a stand still in development, but it should have been way beyond the 1000m in New Tyin

Pumped HPP using ultra high head in unlined tunnels

In Italy some high head pumped storage facilities have been built.
Likely not unlined!
The others are low to medium head
Information on lining concept, or unlined is not disclosed
Have to assume that they are lined and that Norway is front runner in unlined concepts

1000 MW and Larger Pumped Hydro Installations Worldwide

Electronic Storage Association

There are 40 pumped hydro facilities with capacities of 1000 MW or greater worldwide, representing 6 continents and 13 countries.

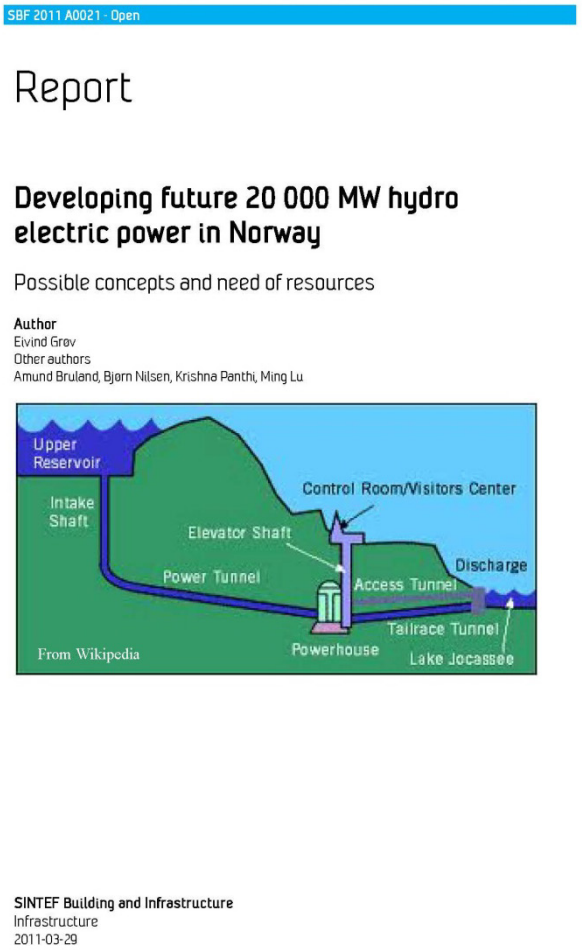
Location	Plant Name	On-Line Date	Hydraulic Head (m)	Max Total Rating (MW)	Hours of Discharge	Plant Cost
Australia	Tumut 3	1973		1690		
China	Tianhuangping	2001	590	1800		$1080 M
	Guangzhu	2000	554	2400		
France	Grand Maison	1987	955	1800		
Germany	Markersbach	1981		1050		
	Goldisthal	2002		1060		$700 M
Iran	Siah Bisheh	1996		1140		
Italy	Piastra Edolo	1982	1260	1020		
	Chiotas	1981	1070	1184		
	Presenzano	1992		1000		
	Lago Delio	1971		1040		
Japan	Imaichi	1991	524	1050	7.2	
	Okuyoshino	1978	505	1240		
	Kazunogowa	2001	714	1600	8.2	$3200 M
	Mananogawa	1999	489	1200		
	Ohkawachi	1995	411	1280	6	
	Okukiyotsu	1982	470	1040		
	Okumino	1995	485	1036		
	Okutataragi	1998	387	1240		
	Shimogo	1991	387	1040		
	Shin Takesagawa	1981	229	1280	7	
	Shin Toyne	1973	203	1150		
	Tamahara	1986	518	1200	13	
Luxembourg	Vianden	1964	287	1096		
Russia	Zagorsk	1994	539	1200		
	Kaishador	1993		1600		
	Dneister	1996		2268		
South Africa	Drakensbergs	1983	473	1200		
Taiwan	Minghu	1985	310	1008		$866 M
	Mingtan	1994	380	1620		$1338 M
U.K./Wales	Dinorwig	1984	545	1890	5	$310 M
U.S.A./CA	Castaic	1978	350	1566	10	
	Helms	1984	520	1212	153	$416 M
USA/MA	Northfield Mt	1973	240	1080	10	$685 M
USA/MI	Ludington	1973	110	1980	9	$327 M
USA/NY	Blenheim-Gilboa	1973	340	1200	12	$212 M
	Lewiston (Niagra)	1961	33	2880	20	
USA/SC	Bad Creek	1991	370	1065	24	$652 M
USA/TN	Racoon Mt	1979	310	1900	21	$288 M
USA/VA	Bath County	1985	380	2700	11	$1650 M

Pumped HPP using ultra high head in unlined tunnels

On invitation from CEDREN the tunnelling research community at SINTEF/NTNU made a joint report in 2011

Develop 20.000 MW pumped storage in 15 years!!
Current 30.000MW in Norway took a hundred years appr.

This study triggered the idea of introducing Ultra High Head


SBF 2011 A0021 - Open

Report

Developing future 20 000 MW hydro electric power in Norway

Possible concepts and need of resources

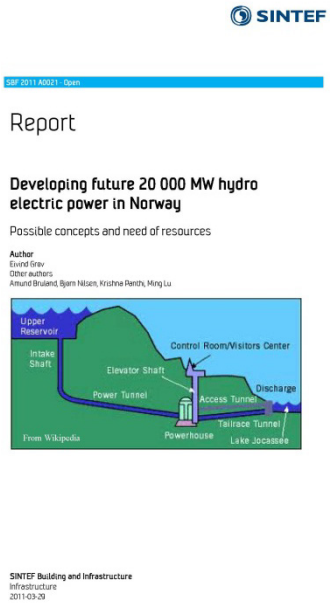
Author
Eivind Grøv
Other authors
Amund Bruland, Bjørn Nilsen, Krishna Panthi, Ming Lu

SINTEF Building and Infrastructure
Infrastructure
2011-03-29

Pumped HPP using ultra high head in unlined tunnels

We used the following as standard solutions for the study:

1000 MW plant and 250 MW plant, head of 445m and 291m respectively, efficiency coeff. = 0.8.
Flow velocity set to 2.3 m/s.
1000 MW has 4 power generation units, 250 MW has 2 units
Layout of each plant is similar to conventional HPP plants consisting of long headrace tunnel, surge shaft, 45° inclination pressure shaft, underground power house, tailrace and access tunnels, approx. 2mill m3 (1000MW) and 0,5mill m3 (250MW) of underground excavation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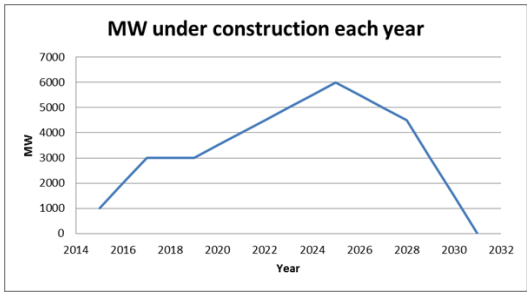
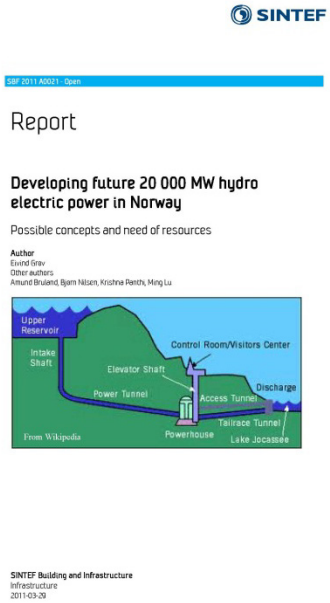


Pumped HPP using ultra high head in unlined tunnels

The conclusions we arrived at in short?

- A demand on appr. 2000m3 rock to be excavated per 1MW installed production capacity
- Average excavation is estimated to be in the range of almost 3 million m^3 per year
- Costs in the range of 3mill NOK per MW
- The peak reaching more than 10 million m^3 annually
- 30.000 man years during the 15 years period
- Is such a development possible???
- If the entire tunnelling industry is involved in HPP-projects only, then **YES (Maybe!)**
- If other projects are ongoing, then **NO (Defenitely)**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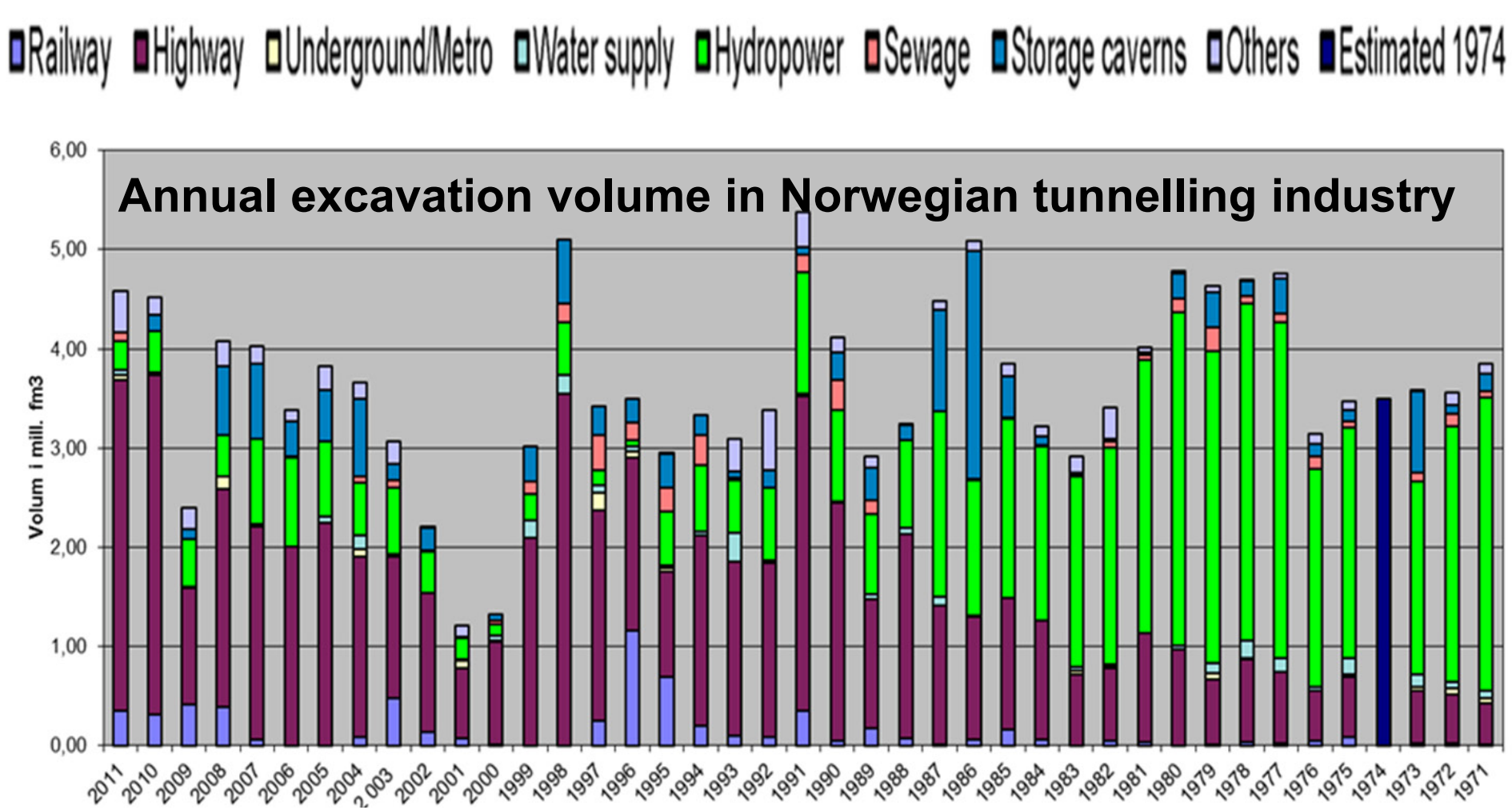
Pumped HPP using ultra high head in unlined tunnels



Pumped HPP using ultra high head in unlined tunnels

Then there is a need to develop new concepts – or new methods!

How can we cut the volume of rock excavation to reduce the construction time and resources needed to produce 1MW?

Man power and equipment constitute a limited resource!

Compact and efficient plants, could be a solution, and included in this is Ultra High Head

Pumped HEP using ultra high head in unlined tunnels

Objective 1:

- Utilize the backbone of Norwegian high head tunnelling technology
- Unlined tunnels, in-situ stresses constitute the confinment
- Increase the head beyond existing utilization of appr. 1000m
- Develop new concepts and increase the compactness of underground HEP facilities

Objective 2:

- Develop and apply new technology for future pumped storage
- Thus reduce the ratio volume of rock/MW installed capacity

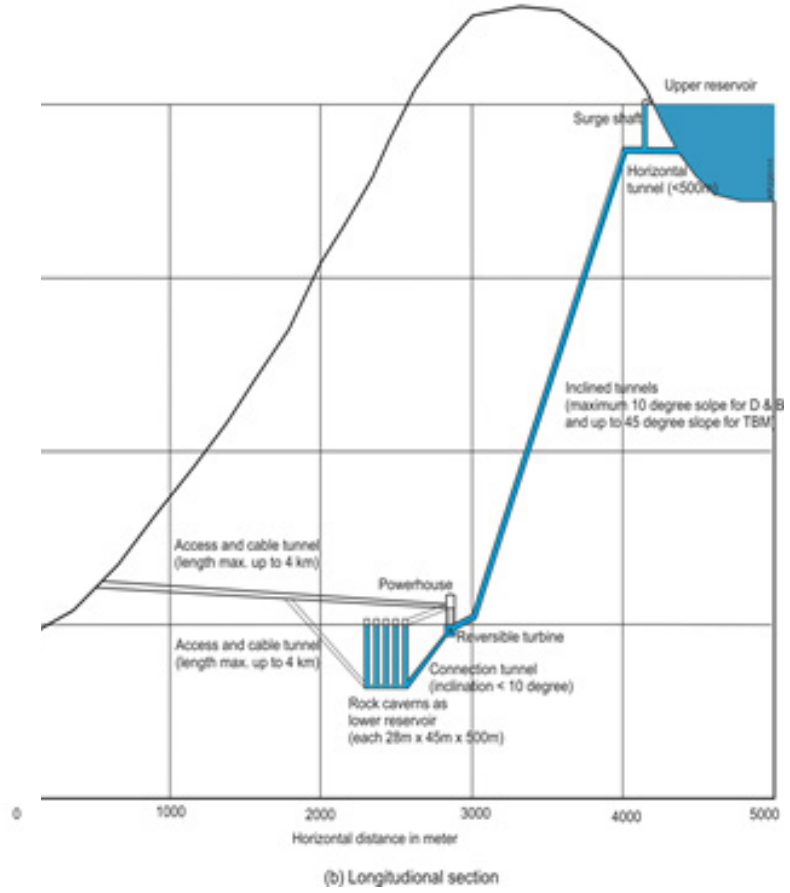
Objective 3

- Develop concepts for cables in long dedicated cable tunnel

Pumped HPP using ultra high head in unlined tunnels

Possibilities:

- Ultra High Head up to eg. 2000m to reduce flow rate
- Reduce the ratio of excavated rock per MW installed capacity
- Reduce the construction time and thus the financial investment
- Improve the stability of the plant during operation
- Increase the efficiency of the plant
- Maintain the upper and lower reservoirs with no additional regulations

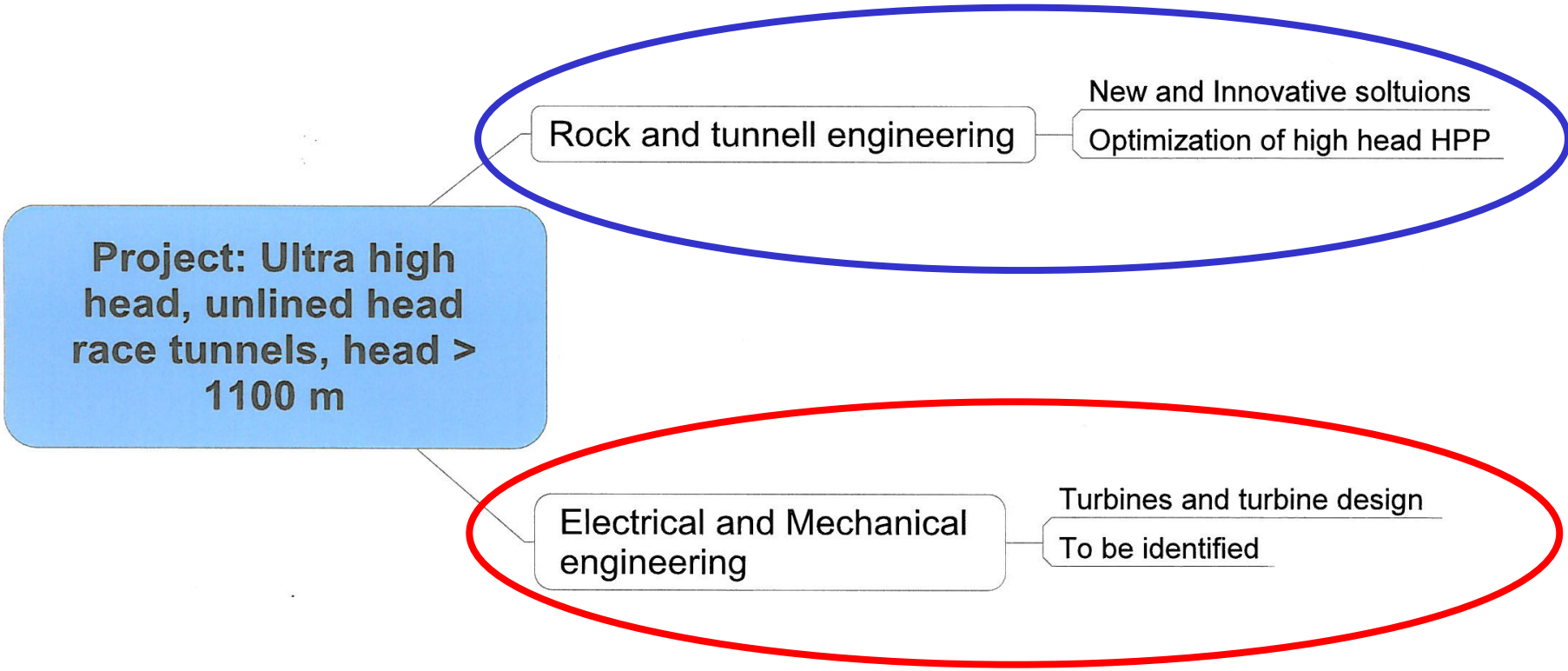


(b) Longitudional section

Compact and efficient plant

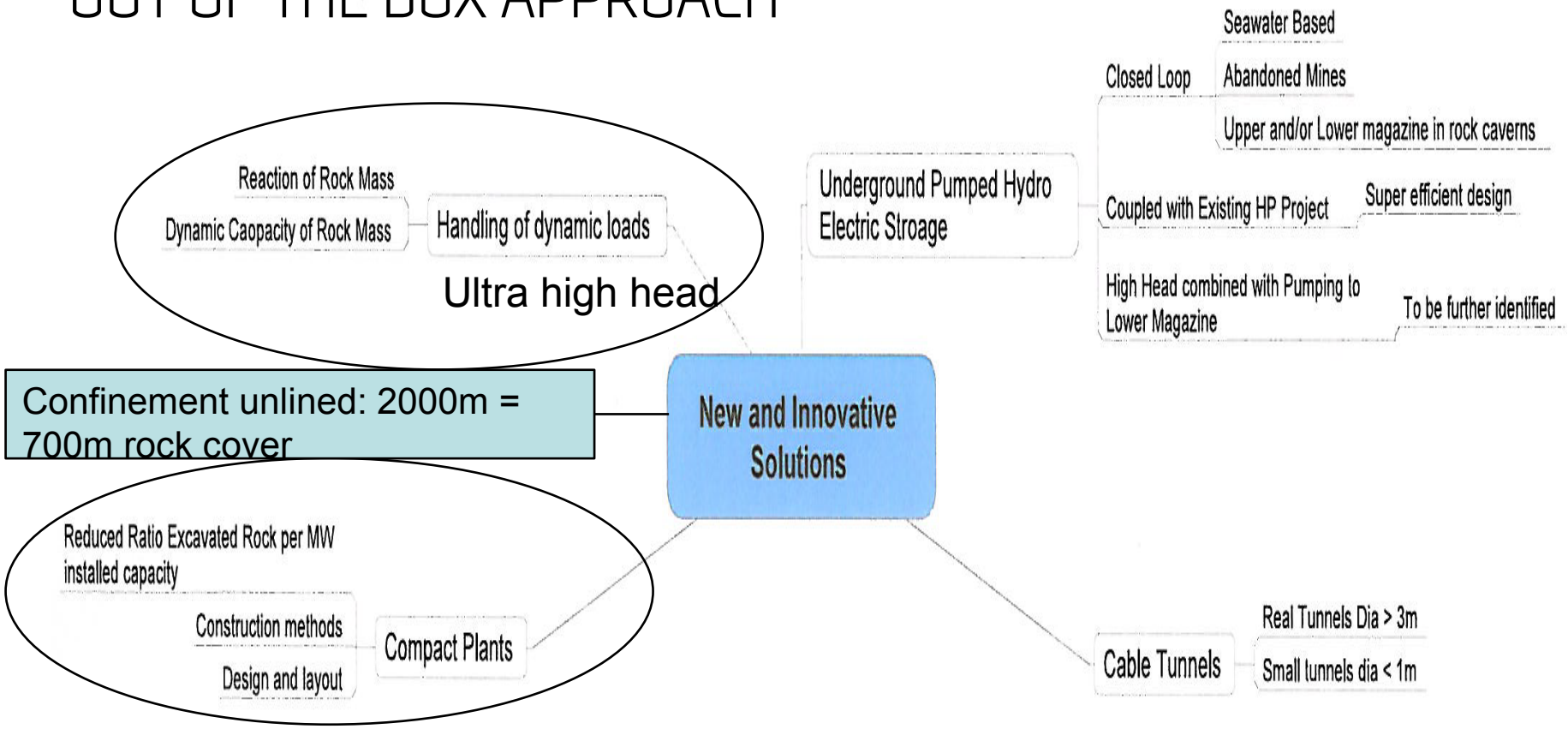
Pumped HPP using ultra high head in unlined tunnels

Could we solve this by Ultra High Head??



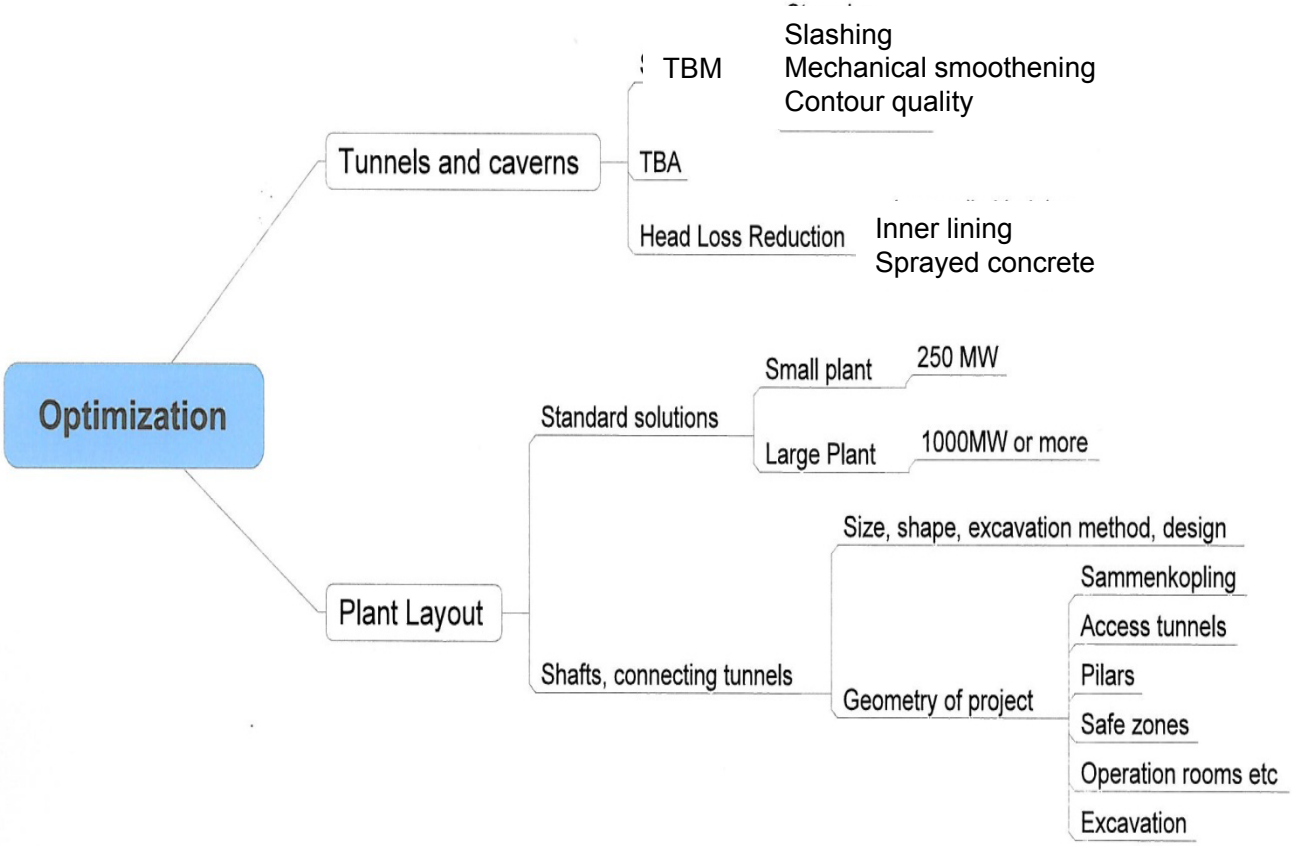
Pumped HPP using ultra high head in unlined tunnels

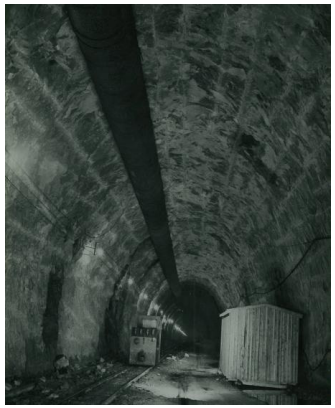
OUT OF THE BOX APPROACH

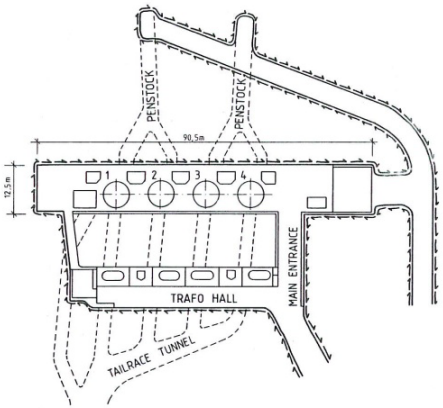


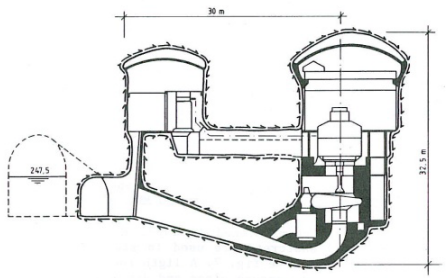
Pumped HPP using ultra high head in unlined tunnels

CONVENTIONAL APPROACH



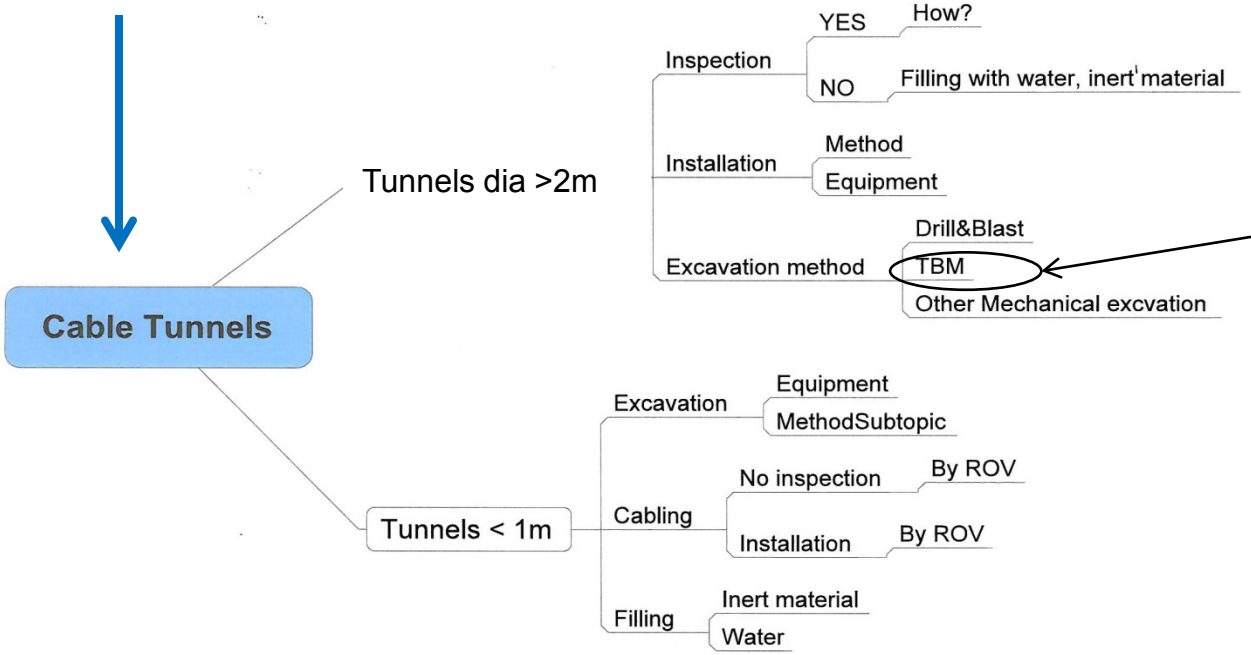






Pumped HPP using ultra high head in unlined tunnels

Developing 20.000MW implies that the topographical implications call for new solutions to bring the electricity to distant consumers. If 'giant masts' is not acceptable, long tunnels 10-20-30km blind boring



Pumped HPP using ultra high head in unlined tunnels

"Compact & efficient pumped hydro power facilities" and "Ultra High Head" needs to study further a variety of aspects, including but not being limited to such as:

- The geometry and layout of the plant
- The hydrodynamics of the plant
- The headrace tunnel system
- The shaft configuration
- The tunnel roughness and possible need of concrete/steel lining
- The surge development and need of surge chambers, surge shafts or other damping
- The excavation method to be employed
- The water velocity
- The turbine and generators specifications
- The down stream configuration of tunnels
- The construction time and costs

AT THE MOMENT A BUNCH OF IDEAS ON RESEARCH TOPICS

Pumped HPP using ultra high head in unlined tunnels

The main challenges today:

We don't know exactly how to get there, what measures to take or what detailed research is needed.

We know though that high ambitions are required to move the traditional HPP forward to "Compact & efficient pumped hydro power facilities" and that Ultra High Head is a possible solutions

THANKS!