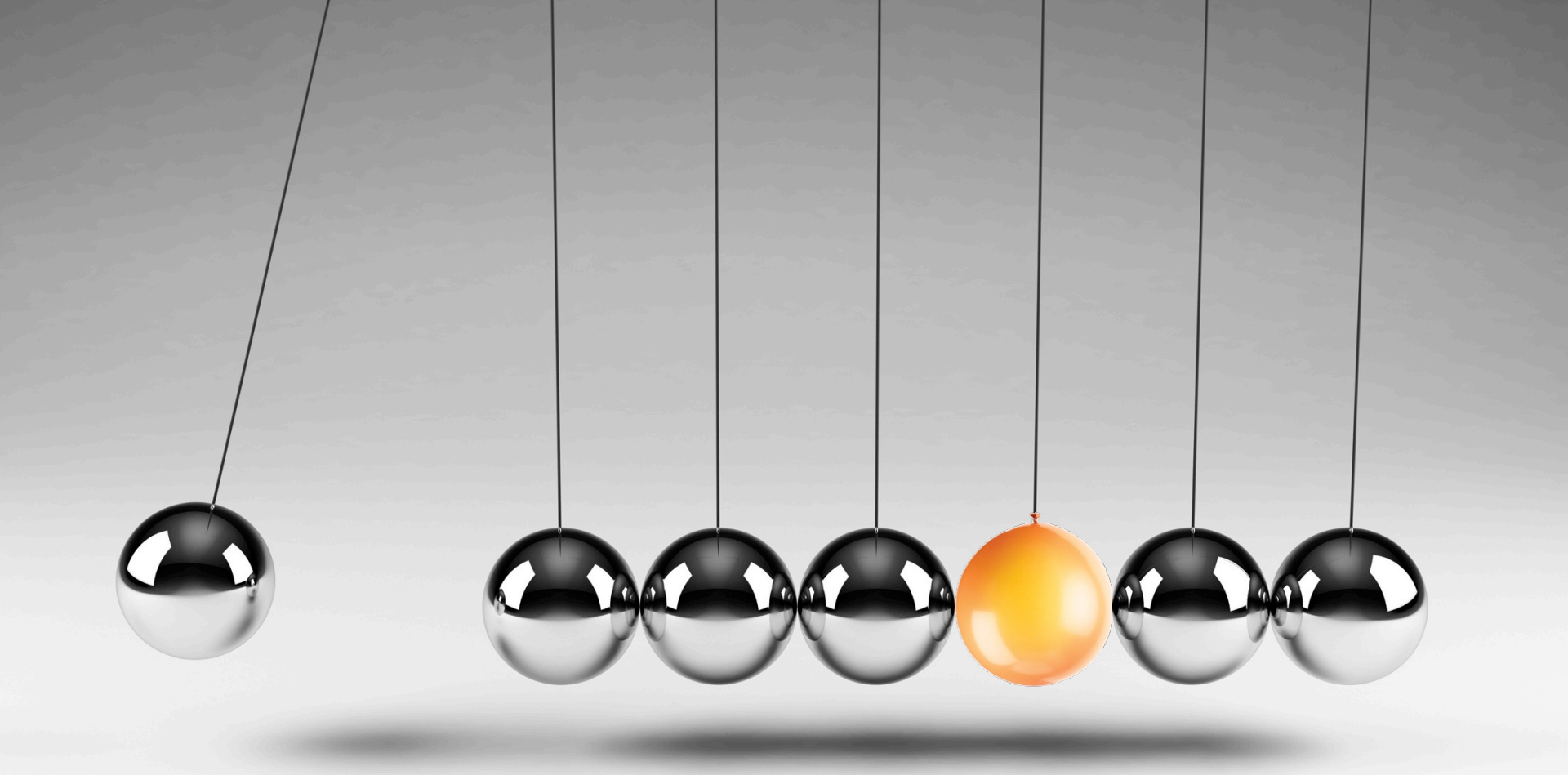
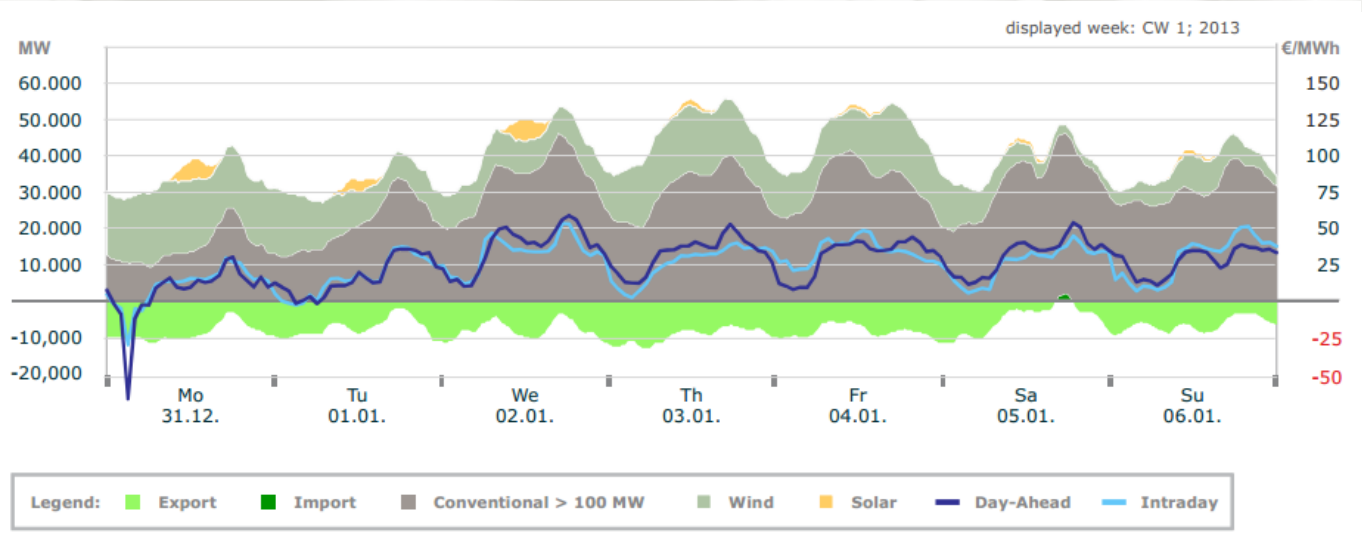


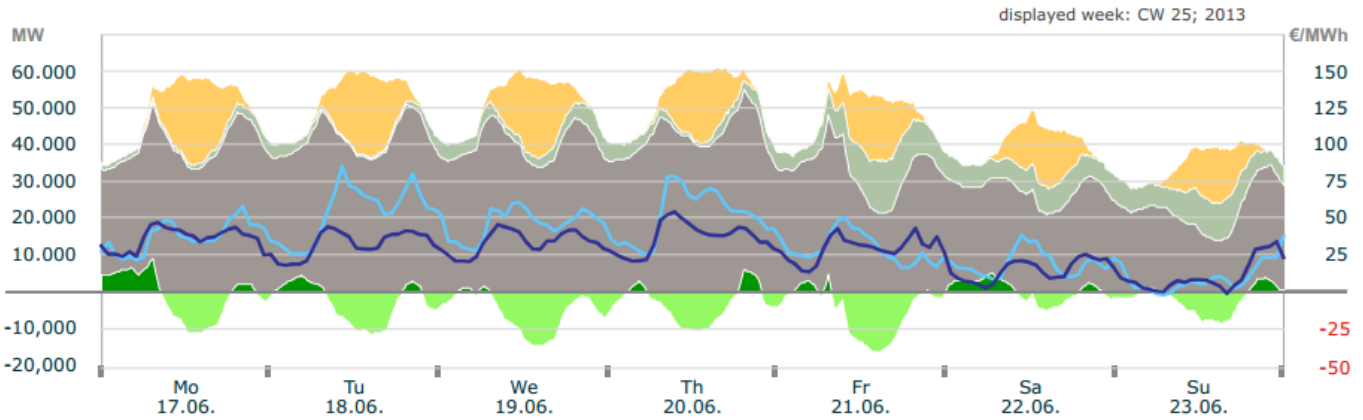
PARKID

“Energiewende” in Germany: what is happening at a practical level?

Windy week



Sunny week



Traditional bulk energy storage is constrained by geography and geology.

PUMPED HYDRO STORAGE

- NEEDS MOUNTAIN
- ENVIRONMENTAL IMPACT
- LONG PERMITTING AND BUILDING

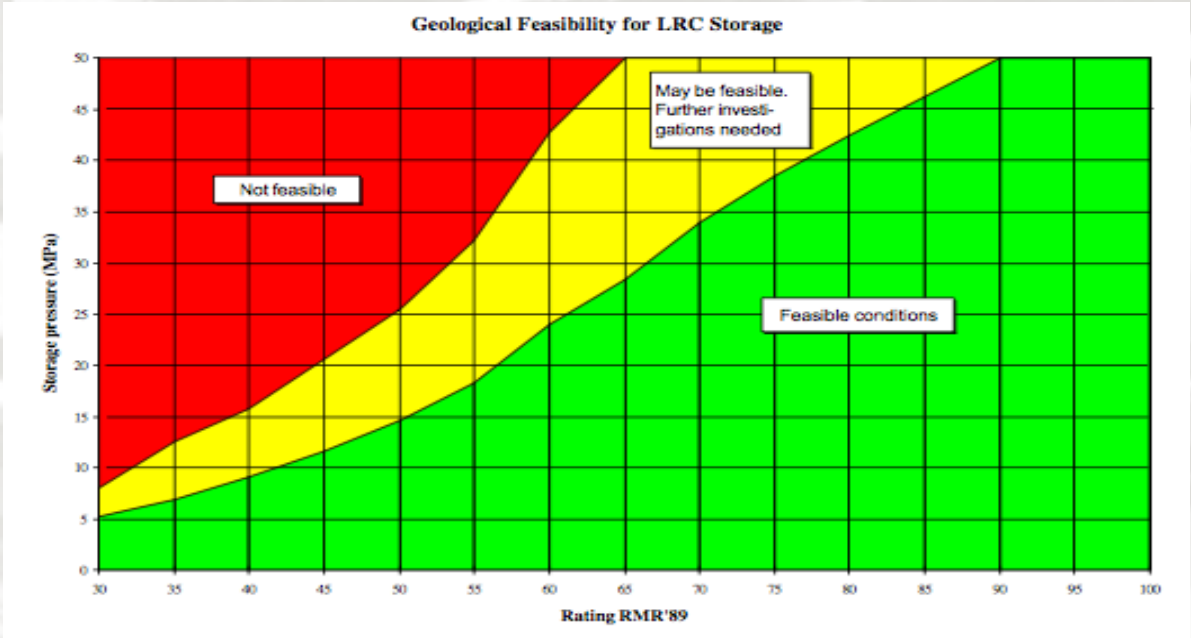
Source: Brookside Storage LLC

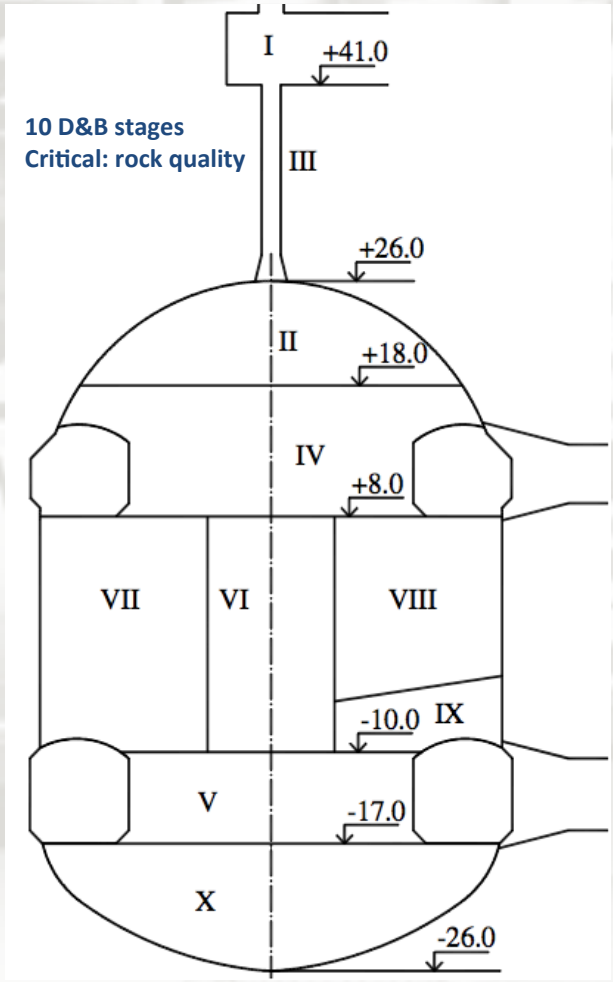
SALT CAVERN

- NEEDS SALT LAYER OR DOME
- CREEP VOLUME REDUCTION
- LONG PERMITTING AND BUILDING

LRC provides proof-of-concept with traditional lining materials and an elaborate construction process.

40,000 m³
1km of tunnels
160m shaft.





10 D&B stages
Critical: rock quality

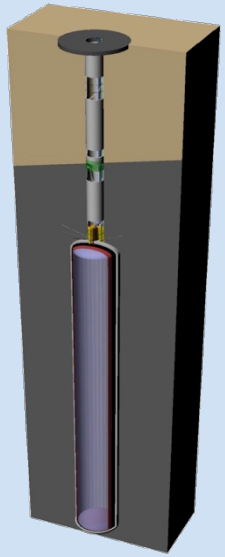
~ 2800 €/m3
~ 100 bar
~ 230 €/kWh

PARKID creates optimum value by combining the best technologies and partners into a CAES system.

KEY CHARACTERISTICS

- Underground Compressed Air Storage
- Drilled modules of 100 – 10,000 m^3
- 100 - 200 bar operating pressure
- 1 to 10 MW
- 1 to 100 MWH

+



KEY BENEFITS

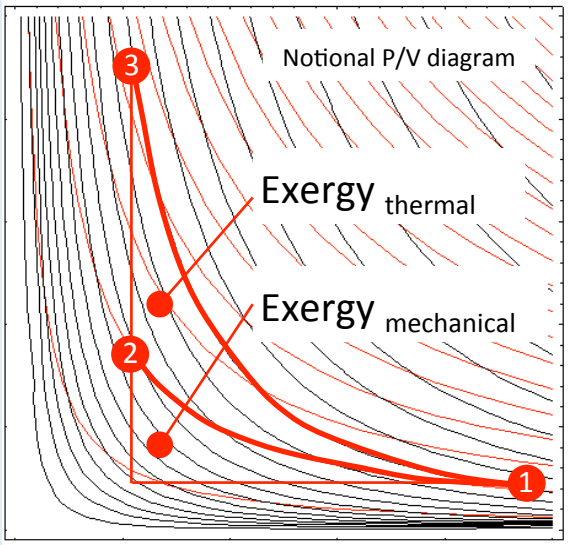
- Economical
- Small footprint at source of variability

Proprietary PARKID BV – Ir. F.J.H. Mouwen MBA

A CAES system consists of a power element and an energy element, which are relatively independent.

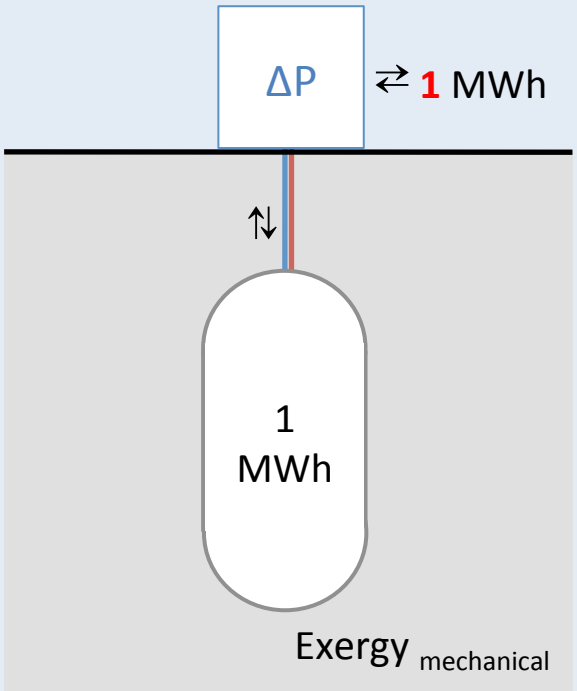
THERMODYNAMICS 101

- Ór: adiabatic 3
- Ór: isothermal 2
- Ór in between: polytrophic



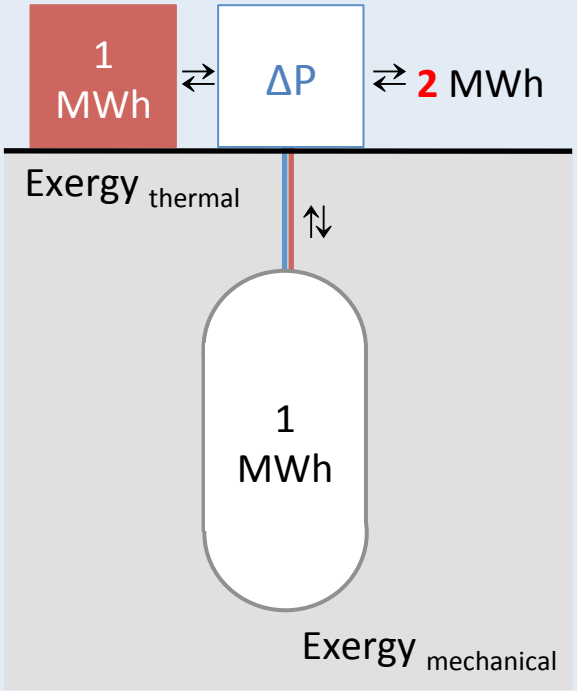
- "Adiabatic exergy ≈ 2x isothermal exergy"

ISOTHERMAL CAES



- Mechanical storage
- Heat exchange

ADIABATIC CAES



- Mechanical storage
- Heat storage

Proprietary PARKID BV – Ir. F.J.H. Mouwen MBA

UCARES' requirements are specific, integrated and complex. Boring technology offers unique benefits.

Drill and blast tunnel

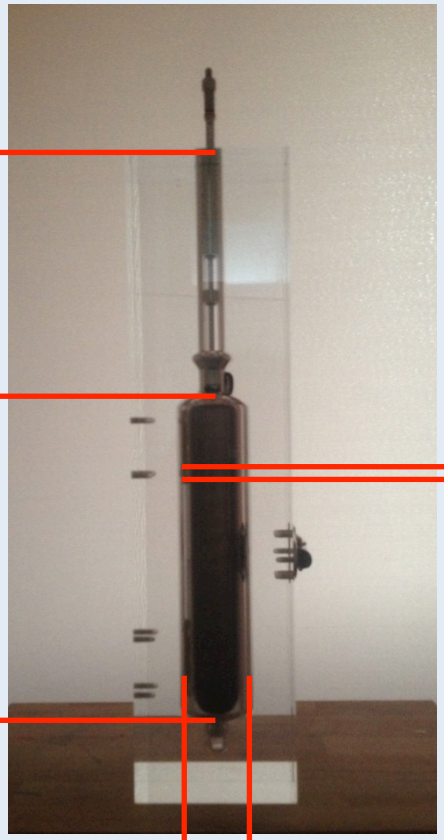
- CHEAP AND FLEXIBLE, BUT:
- MODERATE ACCURACY
- ROUGH SURFACE
- LABOUR INTENSE, SAFETY

Mechanized excavation tunnel

- EQUIPMENT ECONOMICS, BUT:
- VERY HIGH ACCURACY, CONTROL
- SMOOTH LINING SURFACE
- AUTOMATED, PROTECTED, SAFE

PARKID is based on a selection of proven, safe drilling methods available on the market today.

PARKID aims to minimize fixed over variable cost. Adding extra MWh shows low incremental cost.



Fixed cost

Variable cost

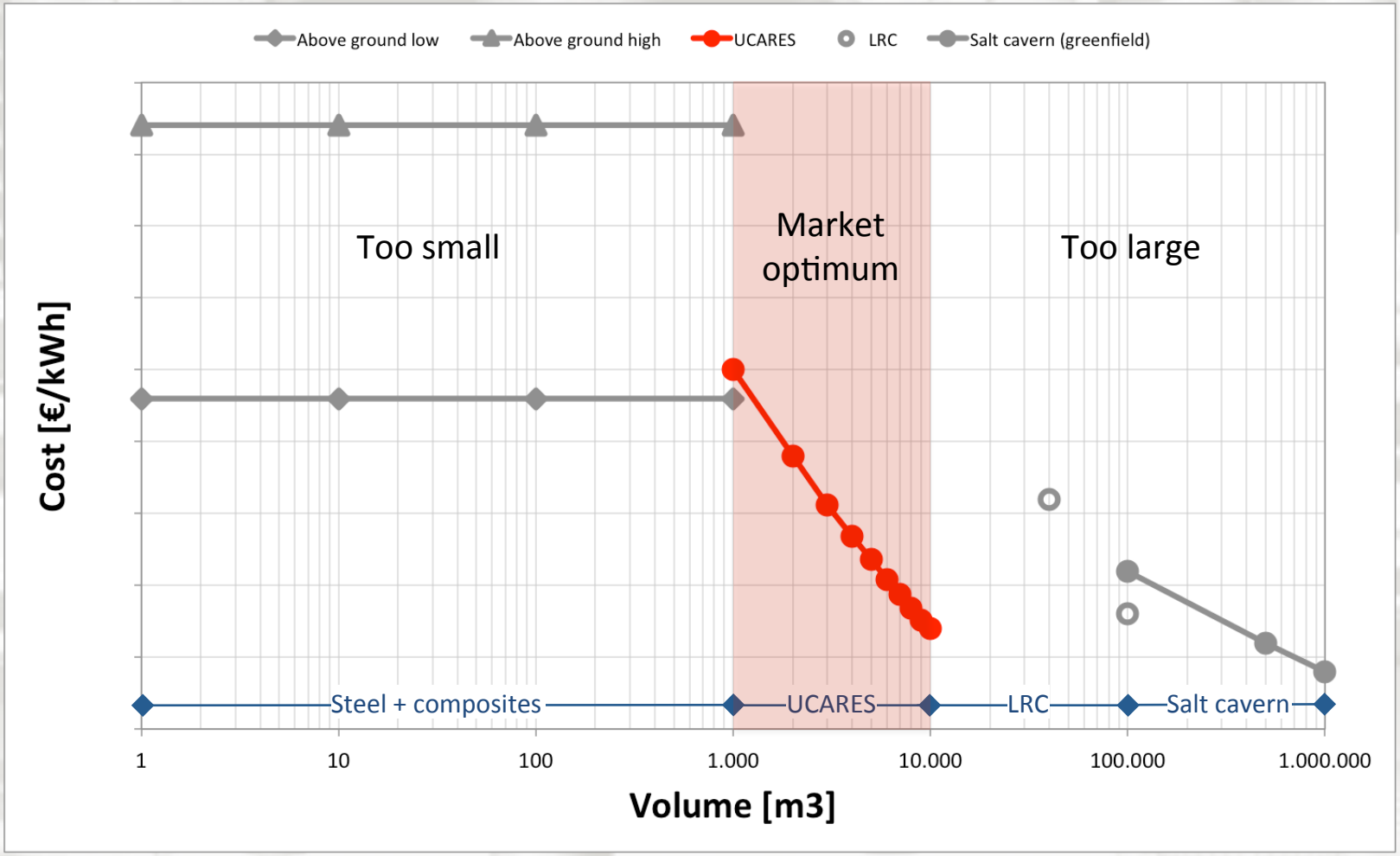
+

Total cost

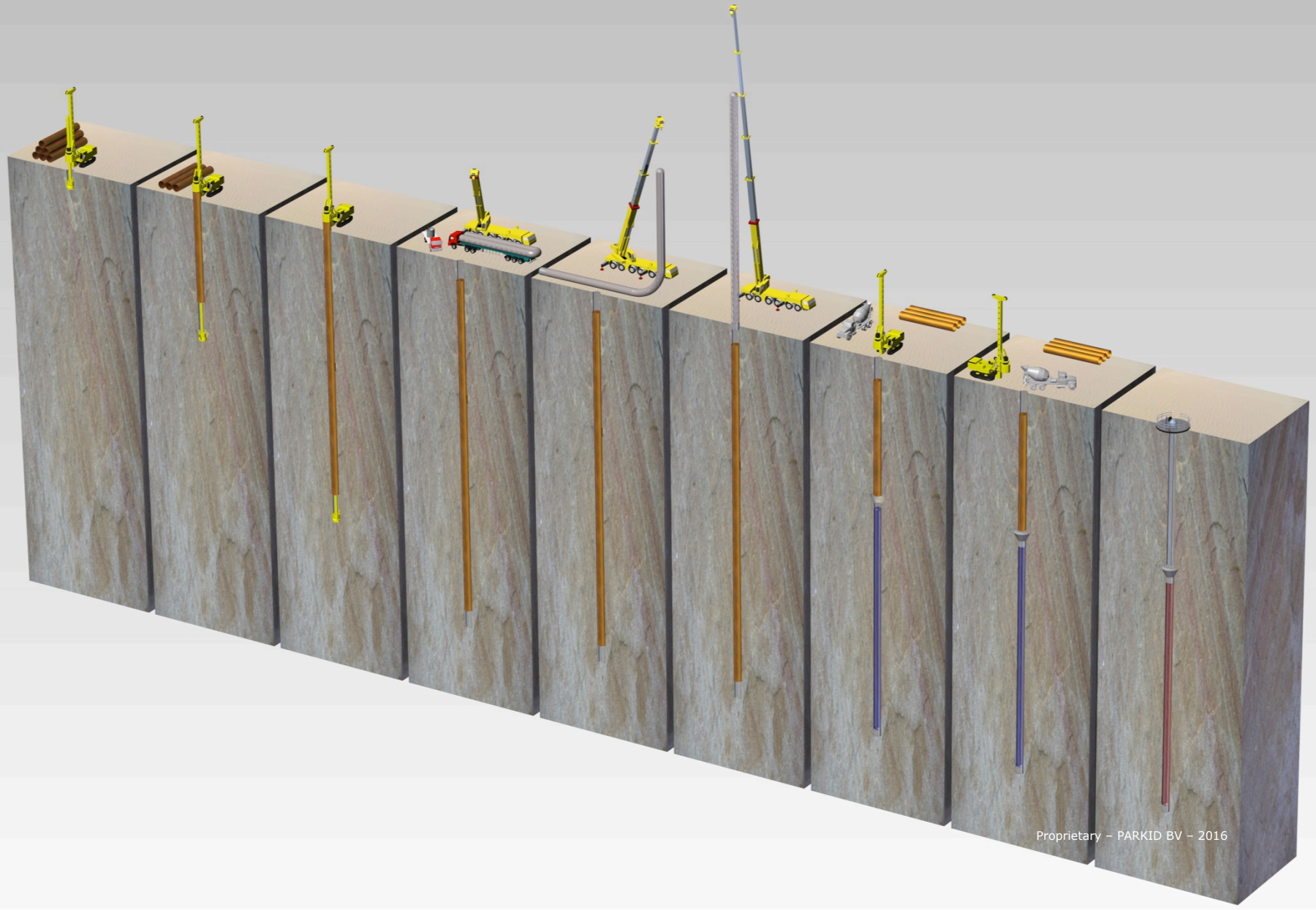
Incremental cost

Scaling effects

Various CAES storage technologies show different economics for different target volumes and markets

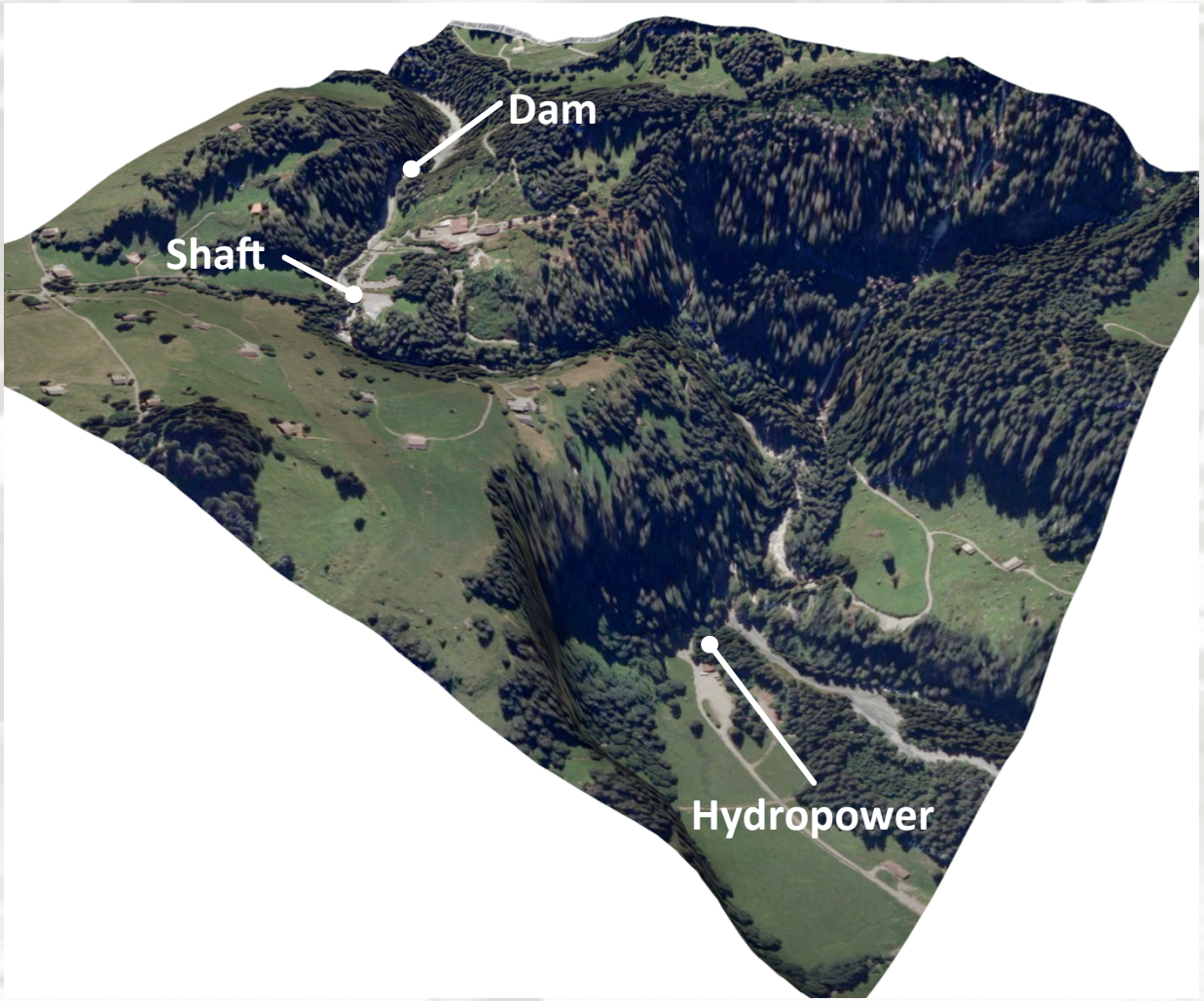


KERN
18166.9

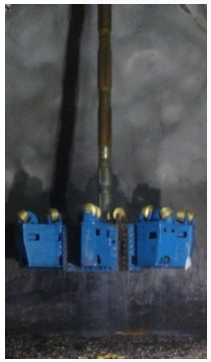


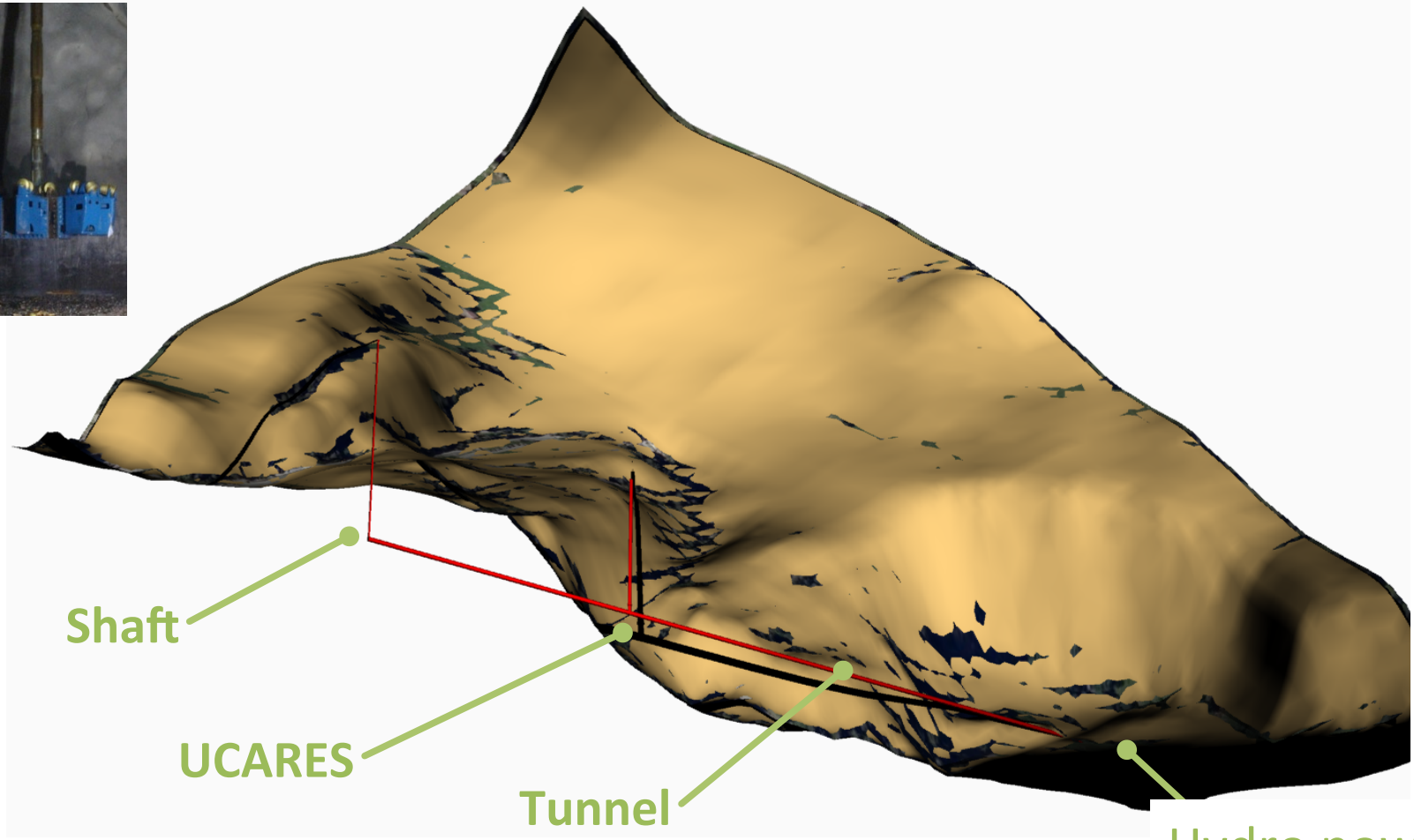
Proprietary – PARKID BV – 2016

CAESCASE: a topographic representation puts an Alpine case situation in notional perspective.



“A look under the bonnet” shows an integration of UCARES with a small Alpine hydropower plant.





A comprehensive energy storage valuation model was used which integrates all relevant inputs.

Technical lay-out

Sources of revenue

Financial parameter

CAPEX

OPEX

VALUATION OF ENERGY STORAGE

Underground compressed air energy storage system

Ir. F.J.H. Mouwen MBA

Proprietary and confidential

ASSUMPTIONS TO NPV SCENARIO ANALYSES

NPV	€ 66.202	IRR	343,2%	€/kWh	0	€/kW	2	OPEX/CAPEX	0 %

Technical assumptions

Power component

Unit installed power	1	[MW]	Nameplate
Unit cycle efficiency "charge"	100	[%]	"Grid-storage"
Unit cycle efficiency "discharge"	100	[%]	"Storage-grid"
Calculated cycle efficiency	100	[%]	"Grid-storage-grid"

Energy component

Storage pressure P2 [8]	100	[bar]
Bottom pressure P1	50	[bar]
Compression volume	1.000	[m3]
Storage temperature	320	[K]
Energy storage density (isothermal compression)	7,4	[kWh/m3]
Energy storage capacity per silo	7,4	[MWh]

Storage system

Power components	1	[-]	System nameplate power capacity	1	[MW]
Energy components	1	[-]	System effective energy storage capacity	7	[MWh]
Duration of 1 full cycle	14:43	[hours:minutes]	Notional maximum # of full cycles per 24h	1,63	[-]

Sources of revenu

Trading scenarios (intraday)

Input from trading scenarios	Y	Manual input Y (yes) or N (no) [1]	Note: OPEX f(MWh traded)
Or:			
Cycles per day	0	[-]	
Energy bought per day	0,00	[MWh]	ROM uniform "block" trading
Energy sold per day	0,00	[MWh]	maximized on daily
Buying cost of energy	0,00	[€/MWh]	100% charge and 100% discharge
Selling price of energy	0,00	[€/MWh]	

Energy from co-location sources [8]

Exergy from secundary heat source per cycle	0,00	[MWh]
Exergy from secundary heat source per day	0	[MWh]
Total energy traded per year	0	[MWh]
Arbitrage revenu per day	0	[€]
Estimated revenu from trading per year	0	[€]

Revenu as storage system provider

Power services [2]	0	[€/MW*week]	Bidding succes rate	100	[%]	Estimated revenu per year	0	[€]
Energy services [2]	0	[€/MWh*week]	Annual change [3]	0	[%]	Estimated revenu per year	0	[€]

Carbon emission certificate trading

Load following carbon emissions	0	[tonnes/MWh]	Carbon trading price	0	[€/tonne]	Estimated revenu per year	0	[€]

Estimated revenu energy related	0	[€]
Estimated revenu power related	0	[€]

Financial assumptions

Project duration	25	[years]	
WACC / discount rate	10,0	[%],	represents risk faced by all investors
Inflation rate	0,0	[%]	
Tax rate [9]	25	[%],	including FIT reductions
Depreciation tax deductable?	Y	Y (yes) or N (no)	
Depreciation period	10	[years]	
Depreciation scheme	SLN	SLN (straight line) or DDB (double declining balance)	
Salvage value	0,1	[%],	as a percentage of CAPEX
Declining factor	2	DDB: larger than 2, or 2 by default	

Support mechanisms

Tariff per traded MWh (notional)	0	[€/MWh]
Production tax credit (PTC) (notional)	0	[€/MWh]
Investment tax credit (ITC)	0	[%]
Real rate (discount rate NPV real method)	10,0	[%]

Charges and fees

APX annual fee	0	[€/year]
Use of System charge (UoS) TSO / DSO	0	[€/MWh]

Capital cost assumptions

Power component CAPEX	1	[€/kW]
Storage volume utilization factor	100%	[%]
Storage component cost	1	[€/m3]
Learning rate energy component [4]	0	[%]
Required volume per unit	1.000	[m3]
Effective energy storage capacity	7	[MWh]

Power / energy cost ratio summary:

Energy component CAPEX [5]	0	[€/kWh]
Power component CAPEX [5]	1	[€/kW]
Energy system CAPEX	0	[€/kWh]
Power system CAPEX	2	[€/kW]
Balance Of Plant CAPEX	0	[€/kW]

Marginal storage component cost

Scale		Storage component cost
1	€	1.000

COST BREAKDOWN STRUCTURE (CBS) ENERGY STORAGE SYSTEM [€]

	System variable capex							System fixed capex (BOP)					General
		Fixed			Fixed (BOP)								
	Energy component	Energy component fixed costs	Co-location heat system costs [8]	Power component	Power components	Civil	Miscallanious	Cabling and grid connection	Control station	Inverters and transformers	Civil	Miscallanious	General cost (management, services, crane hire, contractors)
Capex component input	€ 1.000	€ 0	€ 0	€ 1.000	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	10%
Capex contribution components	€ 2.000							€ 0					€ 200
System capex	€ 2.200												

Operational cost assumptions

	Availability		O&M cost		
Availability "early failure" (25%)	100	[%]	0,00	[€/MWh] [6]	(I.e. 0,0 % of Capex per year)
Availability "useful life" (50%)	100	[%]	0,00	[€/MWh] [6]	(I.e. 0,0 % of Capex per year)
Availability "wear out" (25%)	100	[%]	0,00	[€/MWh] [6]	(I.e. 0,0 % of Capex per year)

Construction energy component	1	[working days]
Working window per year	1	[working days]
Working capital requirements	0	[€]

All power components, transmissions and auxiliary systems installed in year 0

Installations in year 1 — 1

VALUATION OF ENERGY STORAGE

Underground compressed air energy storage system

Ir. F.J.H. Mouwen MBA

Proprietary and confidential

ASSUMPTIONS TO NPV SCENARIO ANALYSES

NPV	€ 66.202	IRR	343,2%	€/kWh	0	€/kW	2	OPEX/CAPEX	0 %

Project value based on future free cash-flows [7]

Year	Units	Annual revenu trading scenario [1] [€]	Annual revenu from primary reserve services [€]	Annual revenu from support mechanisms [€]	OPEX [€]	Depreciation - [€]	Operating profit [€]	Operating taxes [€]	NOPLAT [€]	Depreciation + [€]	CAPEX [i.e. net capital expenditures] (salvage value) [€]	ITC [after-tax non-operating income] [€]	PTC [after-tax non-operating income] [€]	**Real** free cash-flow available to all investors (debt+equity) [€]	DCF (real method) [€]	ROIC [%]
0	0										2.200			-2.200	-2.200	
1	1	10.000				198	9.802	2.451	7.352	198				7.550	6.863	334
2	1	10.000				198	9.802	2.451	7.352	198				7.550	6.239	334
3	1	10.000				198	9.802	2.451	7.352	198				7.550	5.672	334
4	1	10.000				198	9.802	2.451	7.352	198				7.550	5.156	334
5	1	10.000				198	9.802	2.451	7.352	198				7.550	4.688	334
6	1	10.000				198	9.802	2.451	7.352	198				7.550	4.261	334
7	1	10.000				198	9.802	2.451	7.352	198				7.550	3.874	334
8	1	10.000				198	9.802	2.451	7.352	198				7.550	3.522	334
9	1	10.000				198	9.802	2.451	7.352	198				7.550	3.202	334
10	1	10.000				198	9.802	2.451	7.352	198				7.550	2.911	334
11	1	10.000					10.000	2.500	7.500					7.500	2.629	341
12	1	10.000					10.000	2.500	7.500					7.500	2.390	341
13	1	10.000					10.000	2.500	7.500					7.500	2.172	341
14	1	10.000					10.000	2.500	7.500					7.500	1.975	341
15	1	10.000					10.000	2.500	7.500					7.500	1.795	341
16	1	10.000					10.000	2.500	7.500					7.500	1.632	341
17	1	10.000					10.000	2.500	7.500					7.500	1.484	341
18	1	10.000					10.000	2.500	7.500					7.500	1.349	341
19	1	10.000					10.000	2.500	7.500					7.500	1.226	341
20	1	10.000					10.000	2.500	7.500					7.500	1.115	341
21	1	10.000					10.000	2.500	7.500					7.500	1.013	341
22	1	10.000					10.000	2.500	7.500					7.500	921	341
23	1	10.000					10.000	2.500	7.500					7.500	838	341
24	1	10.000					10.000	2.500	7.500					7.500	761	341
25	1	10.000					10.000	2.500	7.500		-220			7.720	713	341
Σ		250.000	0		0	1.980					2.200				66.202	

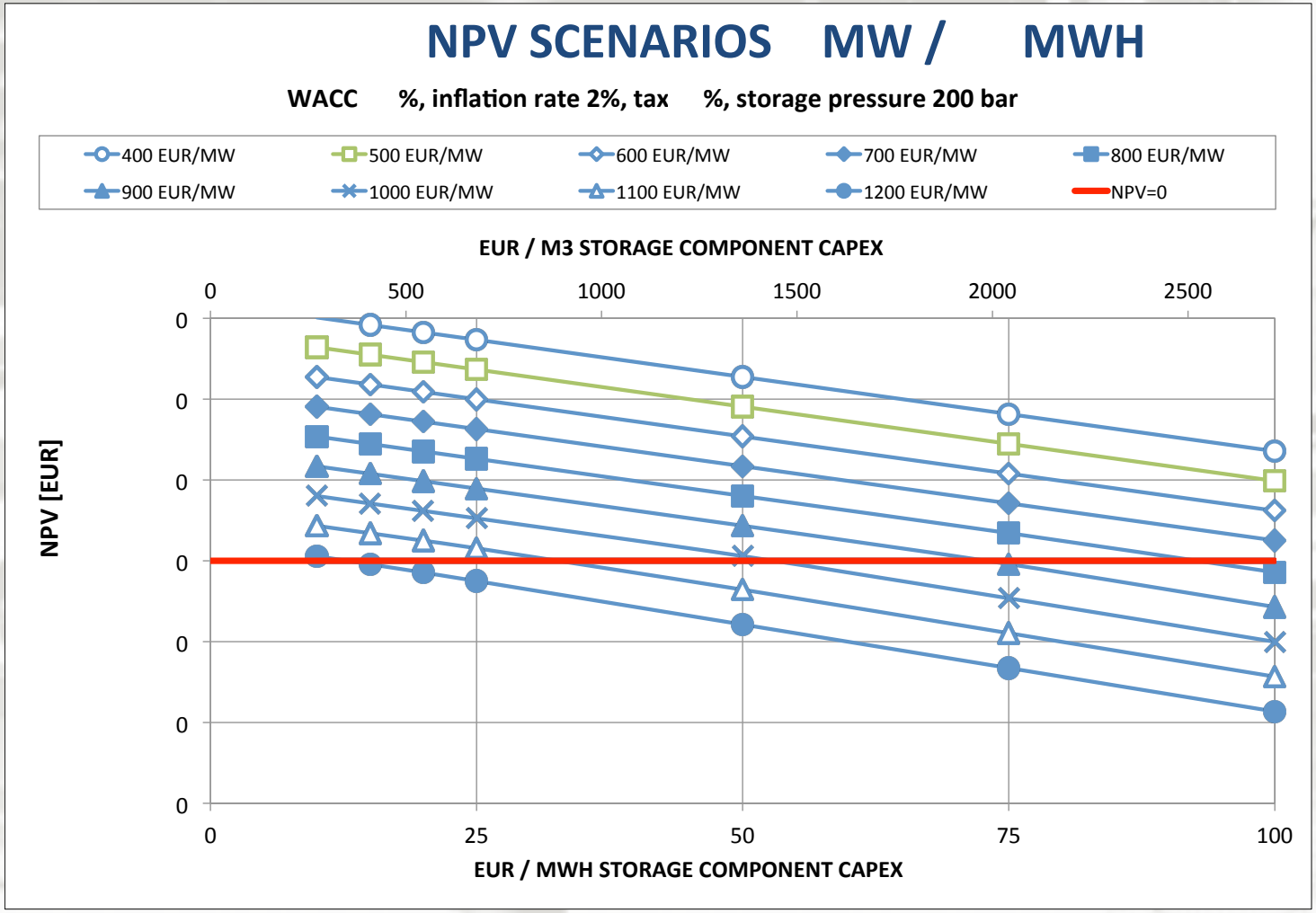
Footnotes

[1] Manual annual revenue input for example based on trading scenario analyses
[2] Primary control, secundary control, tertiary control (minute reserve)
[3] Assumed annual discount reflecting structurally improving (+) or deteriorating (-) market conditions
[4] Improved efficiencies, economies of scale, machine utilization, etc.
[5] Relates to storage respectively power component only
[6] Assumed over both charging and discharging energy flows
[7] Comprising of value of equity and value of debt
[8] Energy from co-location heat sources (low-grade geothermal heat, industrial waste heat). Storage pressure P2 must be adjusted downwards. Investment is included in CBS by separate position
[9] Operator's corporate tax rate

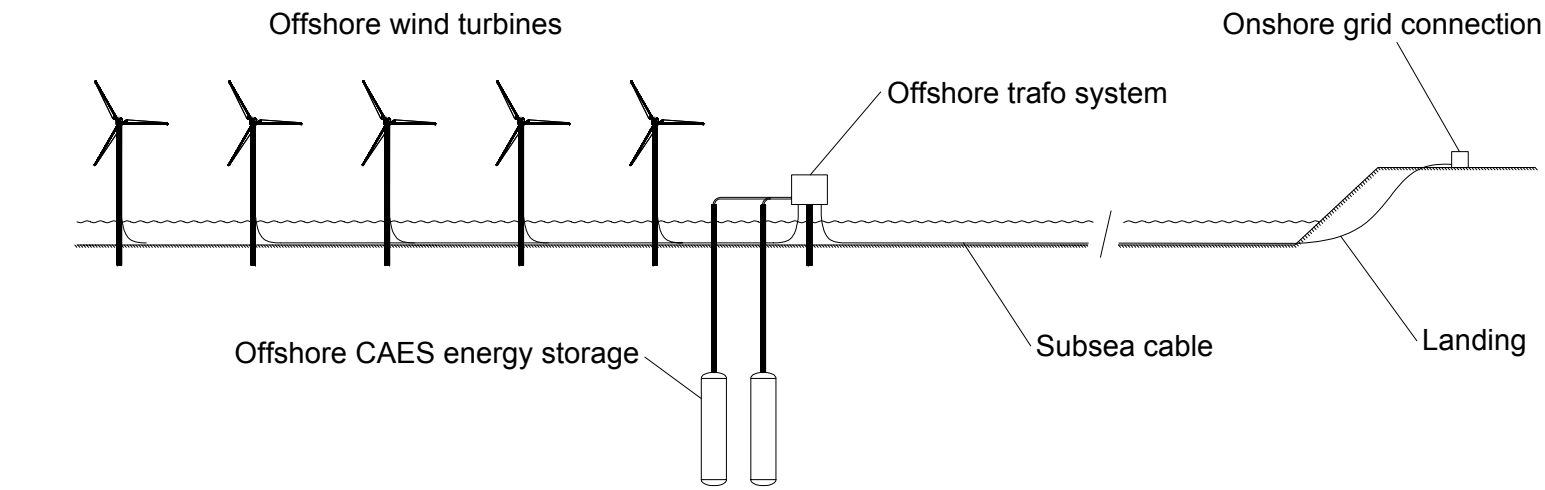
Notes

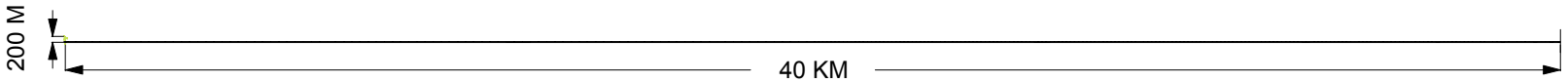
-

Various scenarios showed positive business cases, albeit assuming ‘exemption of grid usage charge’…

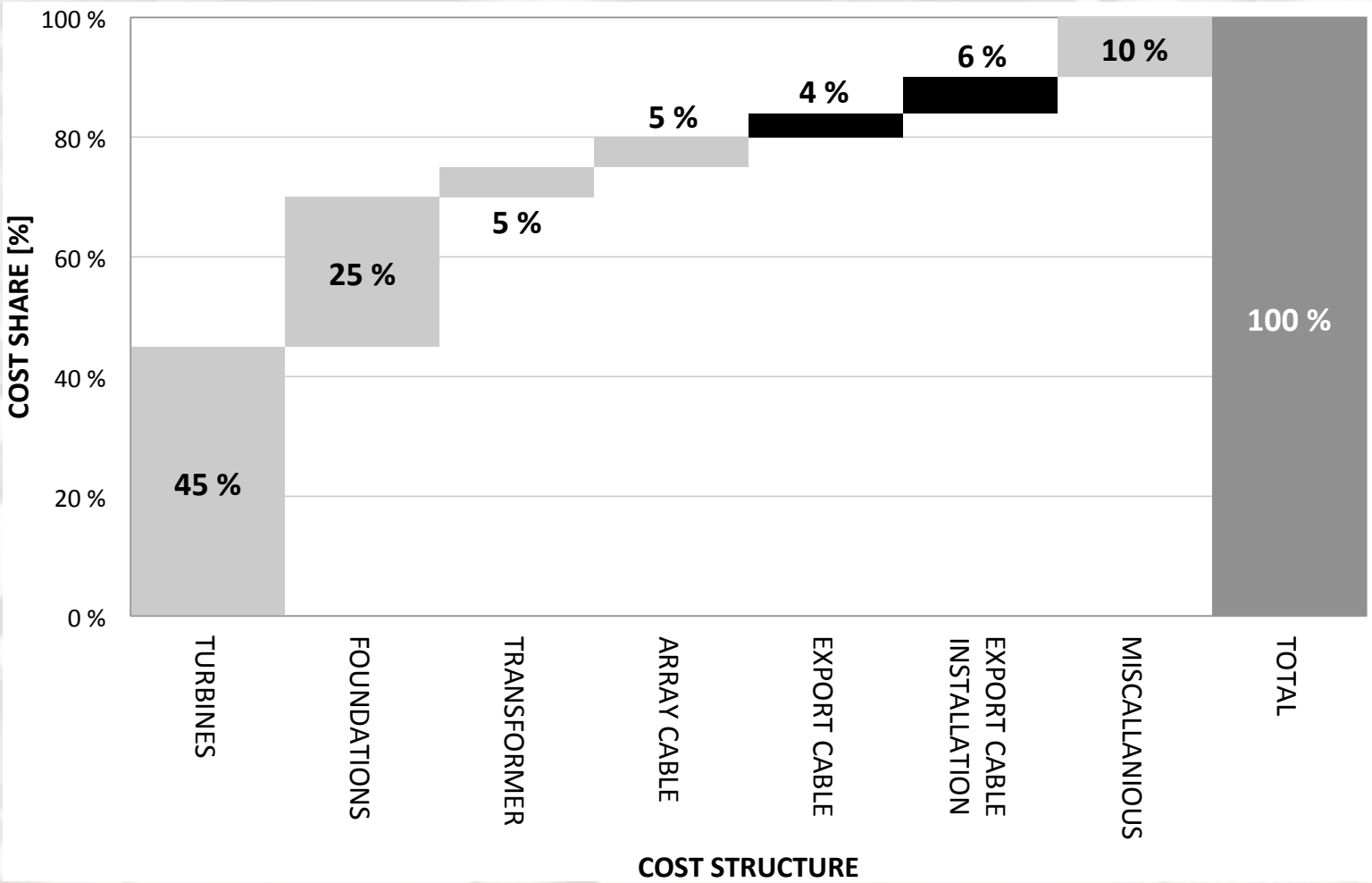


CAESCASE: would the “grid investment deferral” benefit be relevant to offshore wind as well?

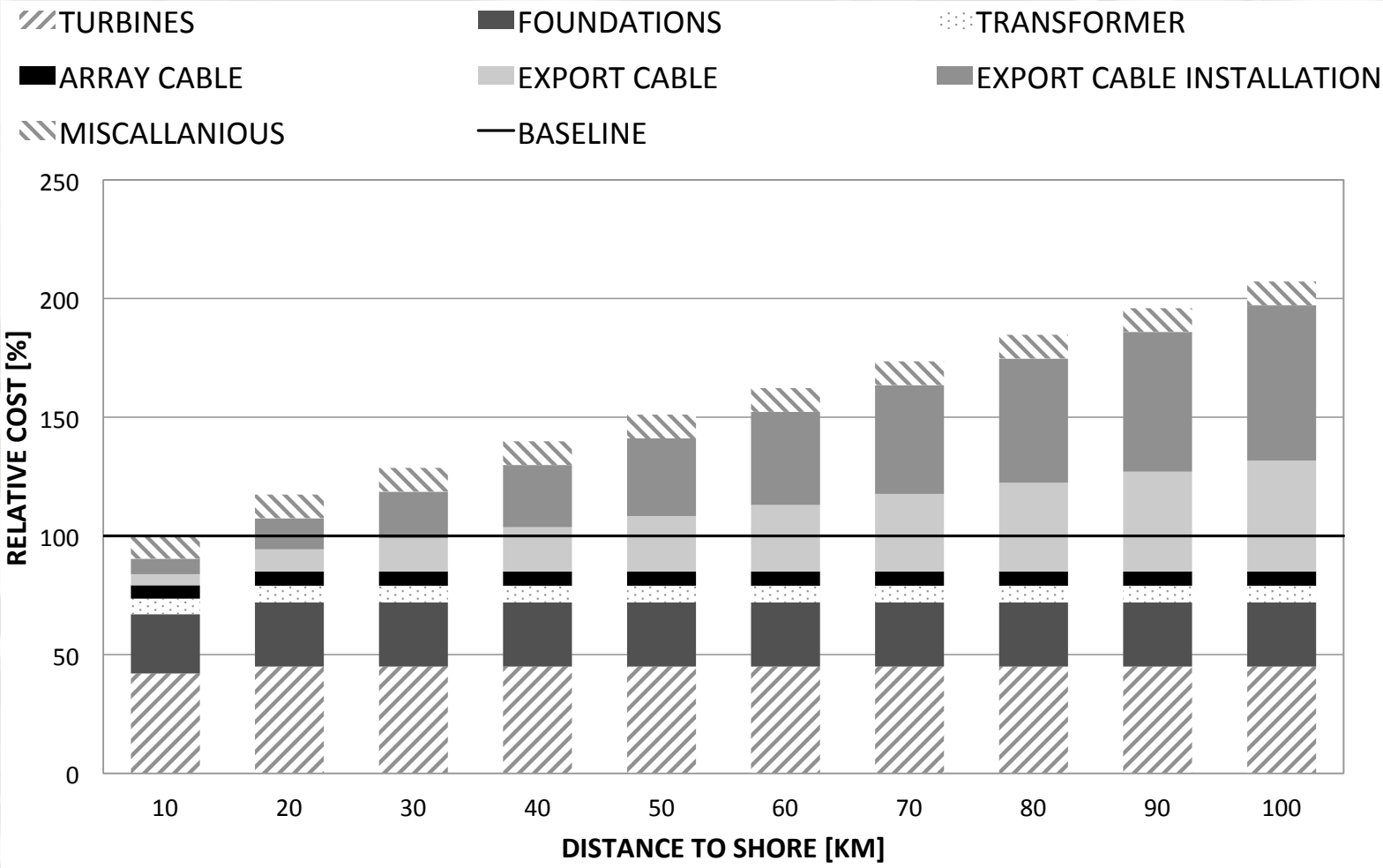




The “copper cost” as a fraction of total cost of an offshore wind system is actually quite small …



… then again, at the large distances to shore the cost of export cables becomes rather substantial.



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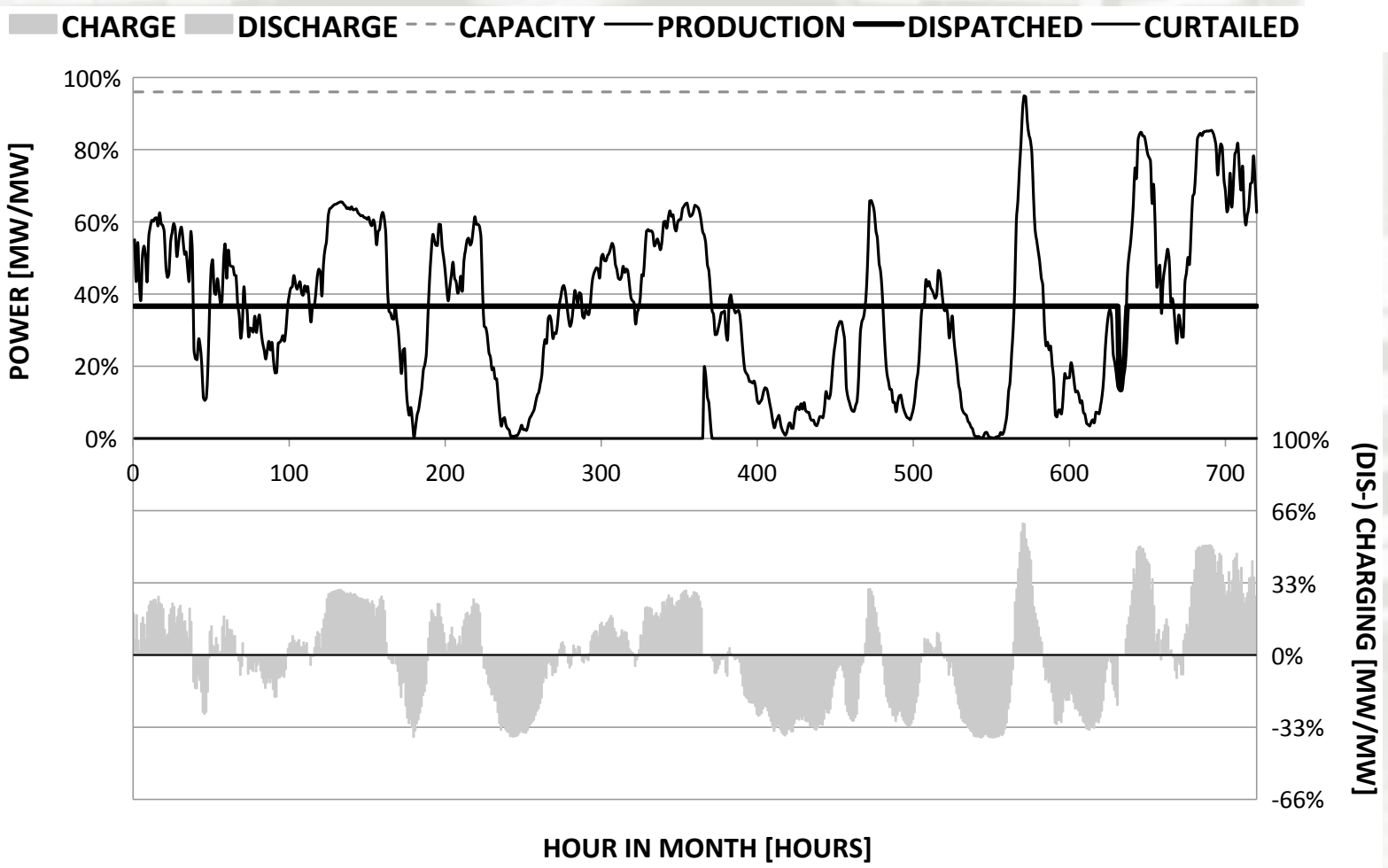
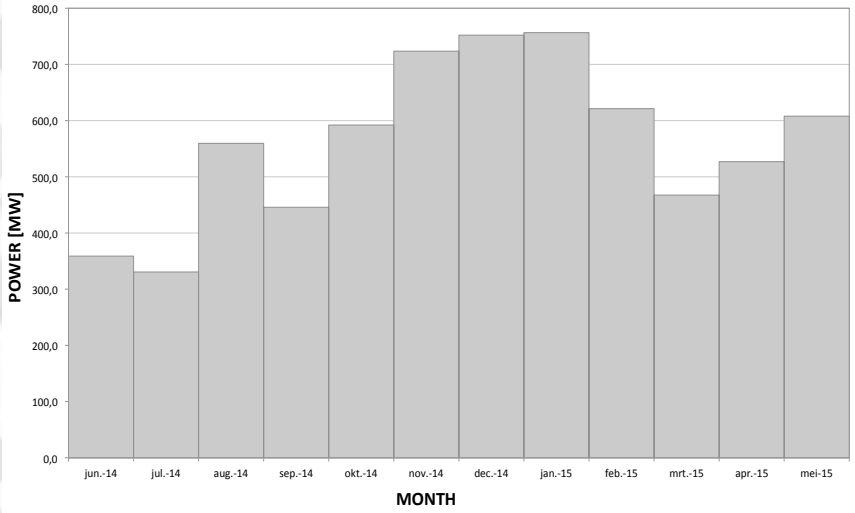
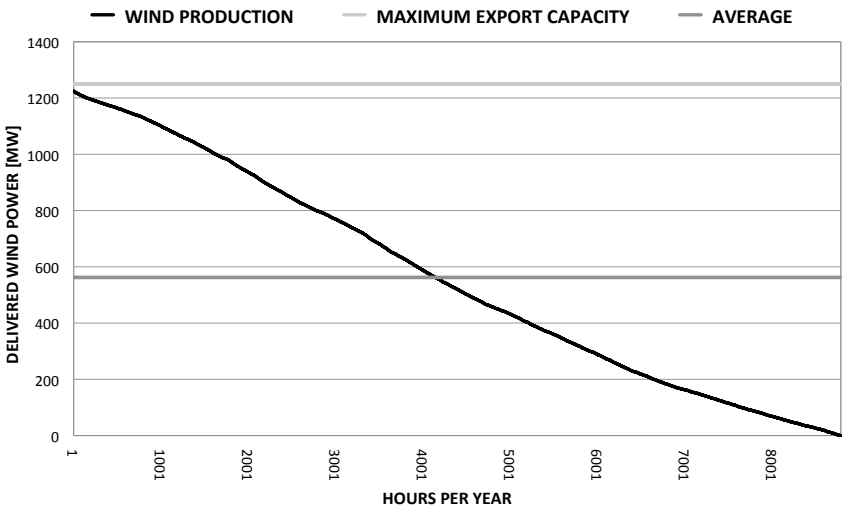
Therefore, would increasing the capacity factor of an export cable with energy storage make sense?

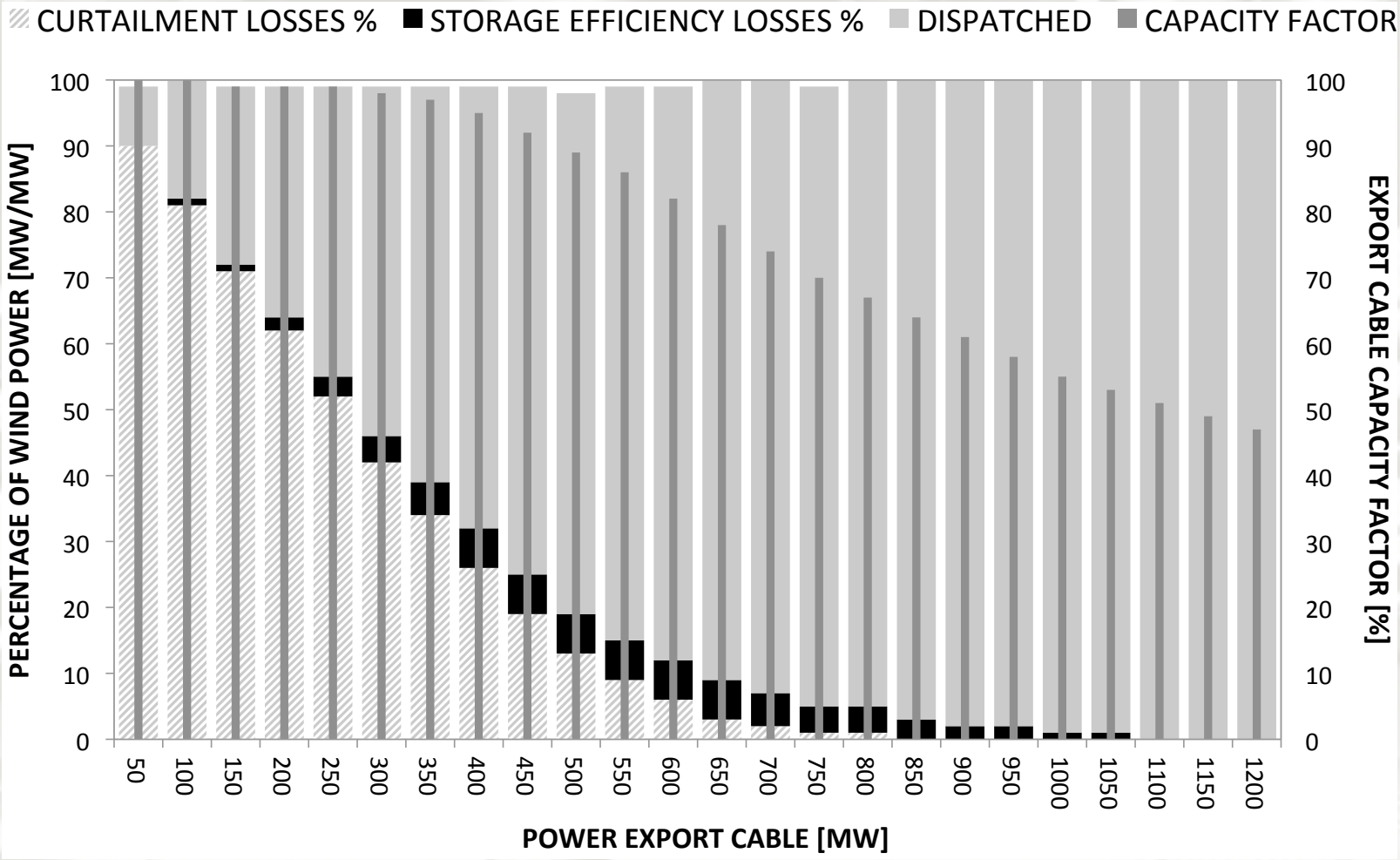


A representative offshore wind production dataset (as good as it publically gets) was analysed





“Energy accounting” was done for a wide range of export cable capacities with storages offshore.



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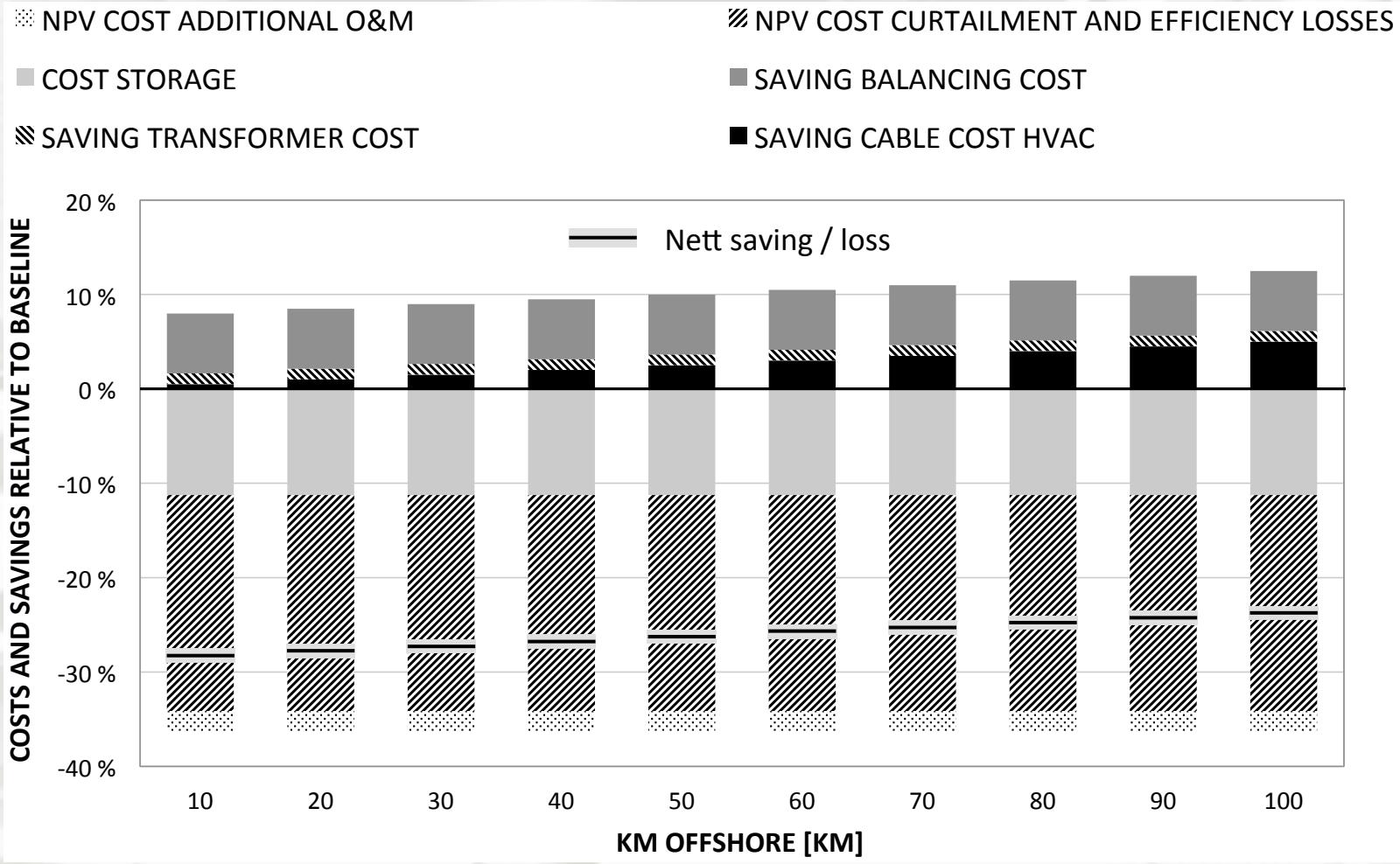
Potential savings on cable costs are outweighed by losses and costs of storage offshore (and reliability)



Climate-change impacts the profitability of ski-resort operators due to a lack of natural snowfall.

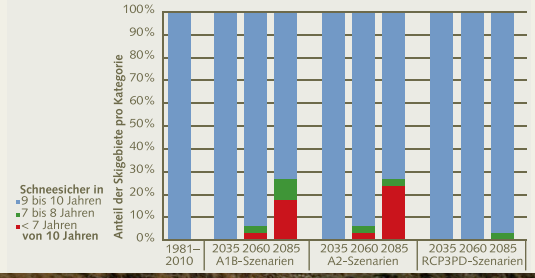
- Multi-billion $/€/CHF ski-industry is identified as highly vulnerable to climate-variability and -change.
- To guarantee the skiing-season for their customers, operators must intensify energy intense snowmaking.
- However, even current snowmaking intensity will not be sufficient to guarantee the desired 100-day business
- This impacts the profitability of ski-resort operators.

TYPICAL SKI FACILITY ENERGY USE

Electrical End Use Data	kWh	Percent	Cost
Compressed Air	5,490,373	53%	$411,778
Water Pumping	2,090,195	20%	$156,765
Lift Drives	2,061,500	20%	$154,613
Lighting	354,440	3%	$ 26,583
Miscellaneous	217,437	2%	$ 16,308
Space Heating	176,565	2%	$ 13,242
Total	**10,390,510**	**100%**	**$779,288**

GUARANTEED SNOW WITHOUT SNOWMAKING

GUARANTEED SNOW WITH SNOWMAKING



POWERSNOW

Artificial snowmaking consumes huge quantities of water and energy. POWERSNOW saves on energy.

A NOZZLE PRODUCES SNOW BY MIXING WATER MIST WITH DECOMPRESSING AIR FOR INSTANT ADIABATIC COOLING.

A "FAN-GUN" ENHANCES THIS EFFECT WITH MULTIPLE AIR-WATER NOZZLES INJECTING INTO A FANNED AIR FLOW.

Water is stored in lakes or extracted from streams; electrical compressors supply compressed air.

POWERSNOW

POWERSNOW uses hydraulic air compression, widely deployed in 1900-era mining operations.

Low-head (10-20m) hydropower source

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Mixing air-bubbles with water at inlet

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Hydrostatic, isothermal air compression

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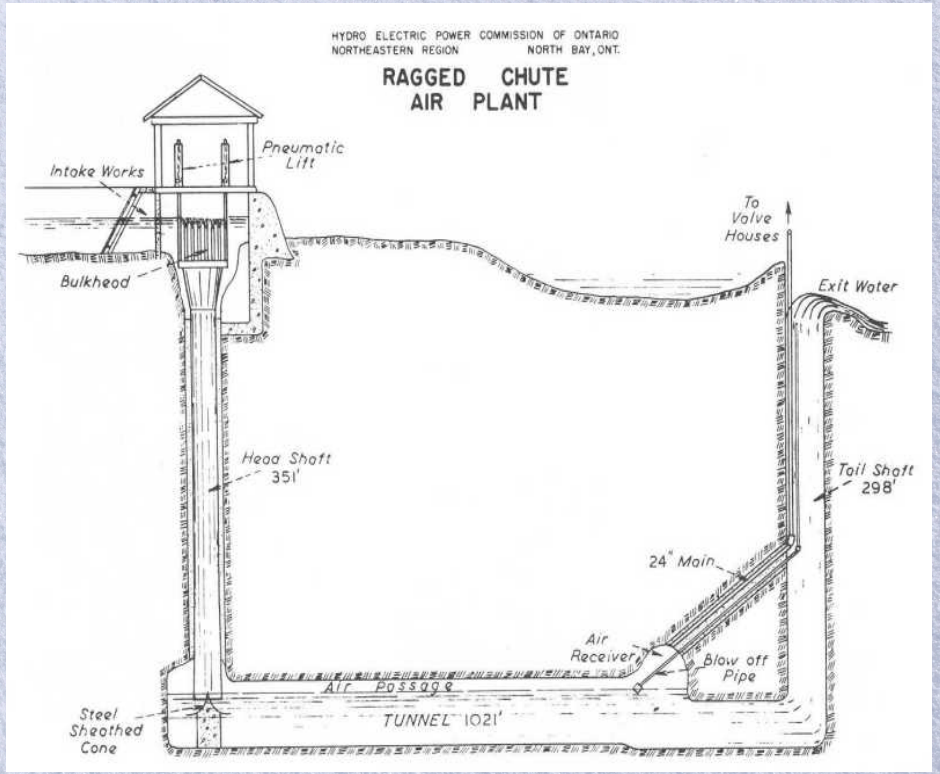
Separation of water and compressed air

↓ ↓

Water continues | Supply dry, cold air

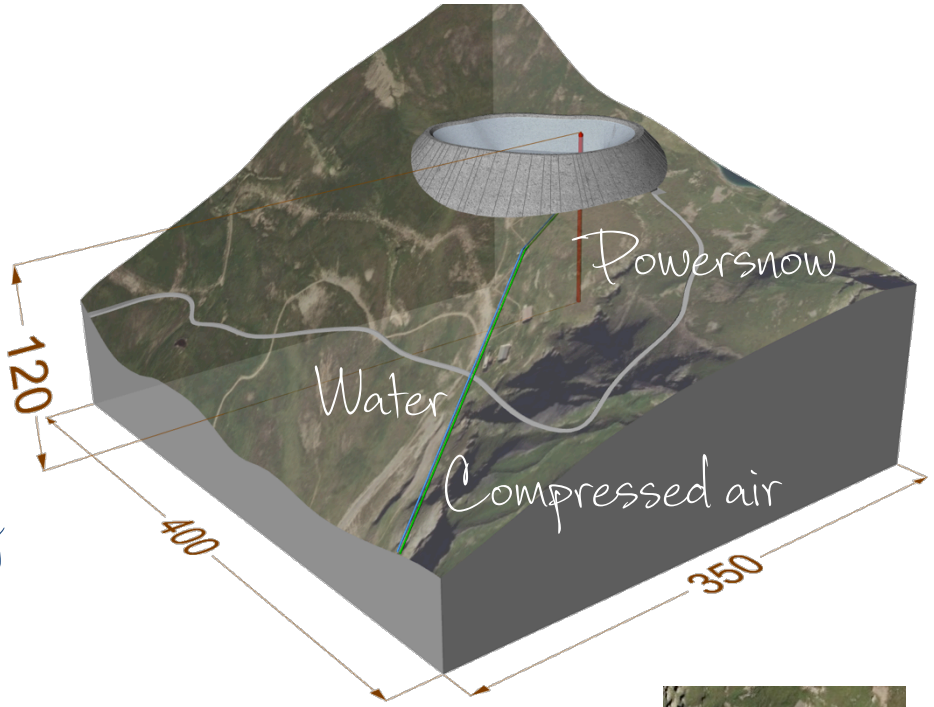


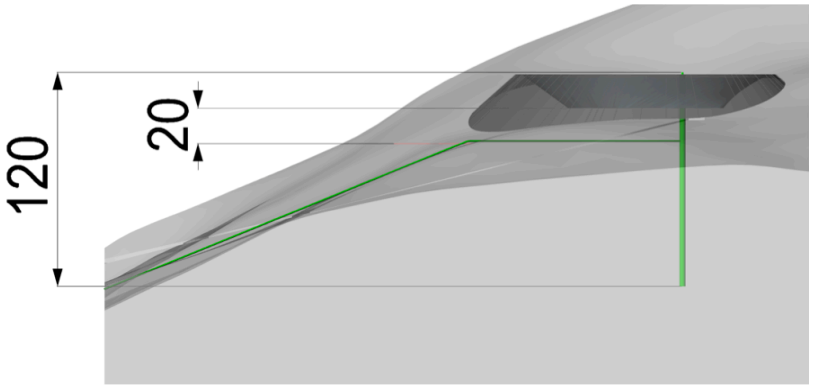
Without moving parts or purchased power (losses), the hydraulic air compressor offers very low OPEX.

POWERSNOW

POWERSNOW is directly driven by hydropower, by-passing electricity generation and compressors.

Notional example: Grindelwald
Volume: 100.000m³
Water flow: 2000m³/h
Shaft diameter: DN400
Air-water ratio <1:1
Water + air used for snowmaking





“The timing is right” to start paddling now, in order to catch the energy storage wave.