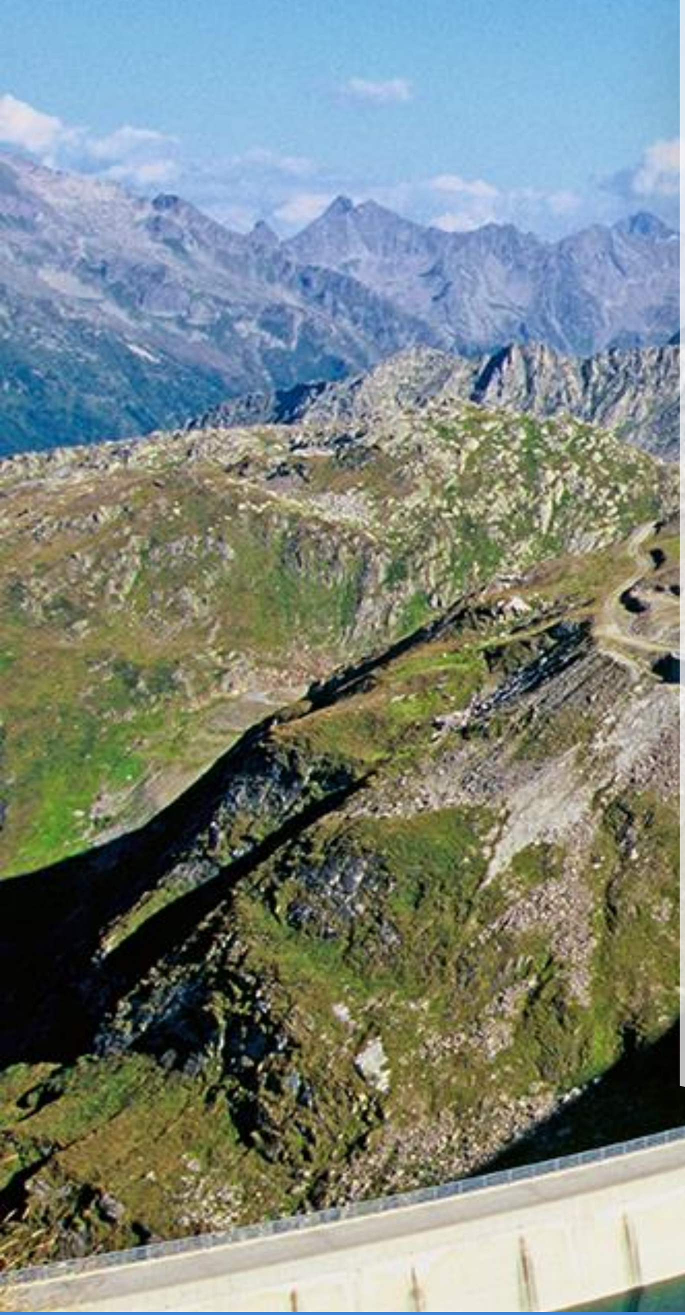
ETIP HYDROPOWER

# ROBERT BOES


## LABORATORY OF HYDRAULICS, HYDROLOGY AND GLACIOLOGY (VAW), ETH ZURICH


Robert Boes is a professor of hydraulic structures and director of the Laboratory of Hydraulics, Hydrology and Glaciology at ETH Zurich. His research interests include sustainable hydropower, dam hydraulics and dam safety, reservoir sedimentation, and flood protection. He is currently president of the Swiss Committee on Dams as well as a board member of the Swiss Association for Water Resources Management and the Energy Science Centre of ETH Zurich.


Funded by
the European Union



ETIP HYDROPOWER

# HYBRIDIZATION OF HYDROPOWER WITH BATTERIES TO REDUCE HYDROPEAKING AND BIODIVERSITY IMPACTS IN RIVERS

Robert Boes

Professor and Director

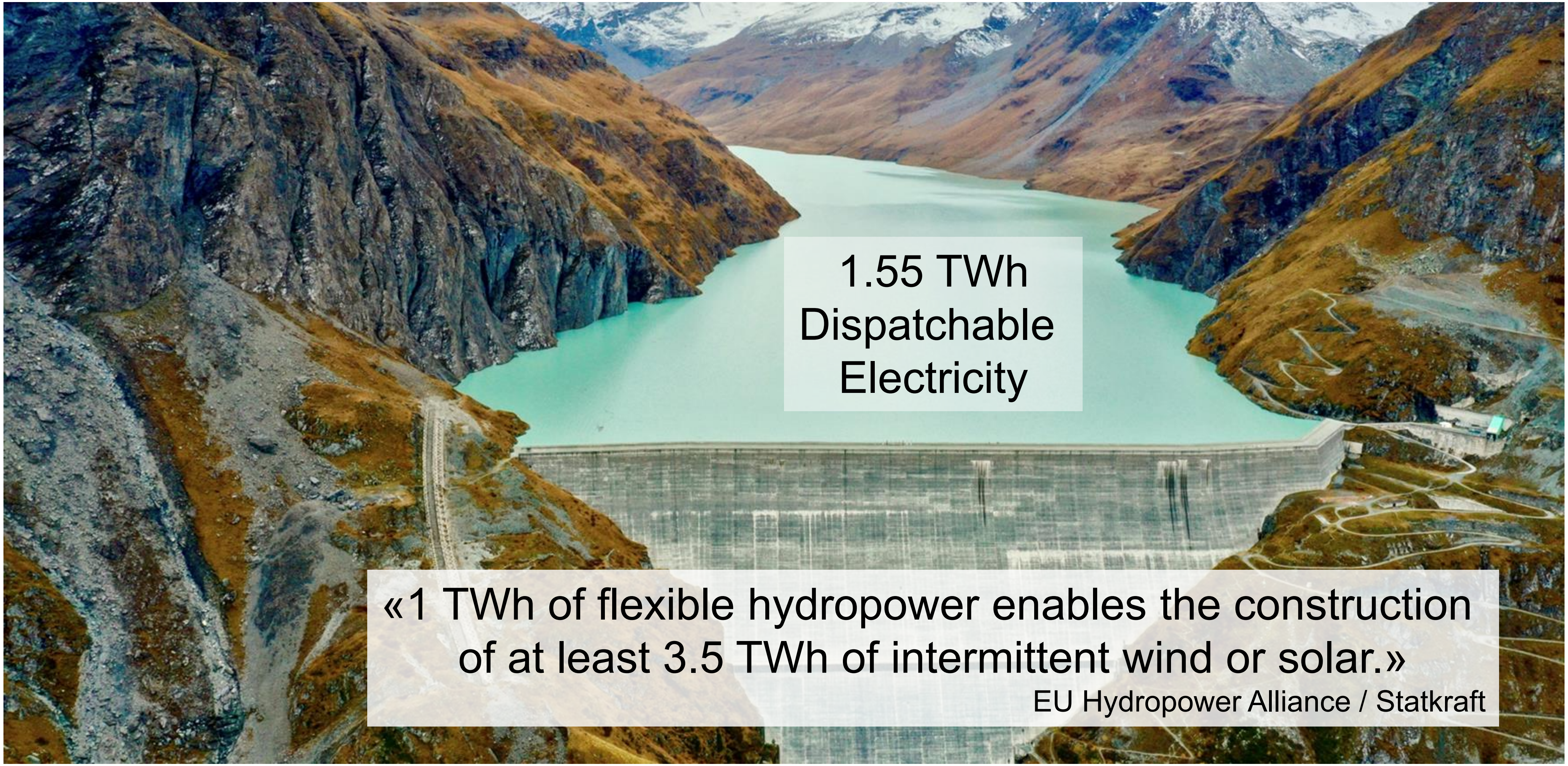
Laboratory of Hydraulics, Hydrology and Glaciology (VAW), ETH Zurich

Funded by the European Union

# Outline

1. Storage Hydropower & Hydropeaking
2. Hydropeaking Mitigation Concepts
3. Hybridization with Batteries
4. Operation
5. Case Study
6. Conclusions

# Storage Hydropower – Grande Dixence / Lac des Dix (CH)

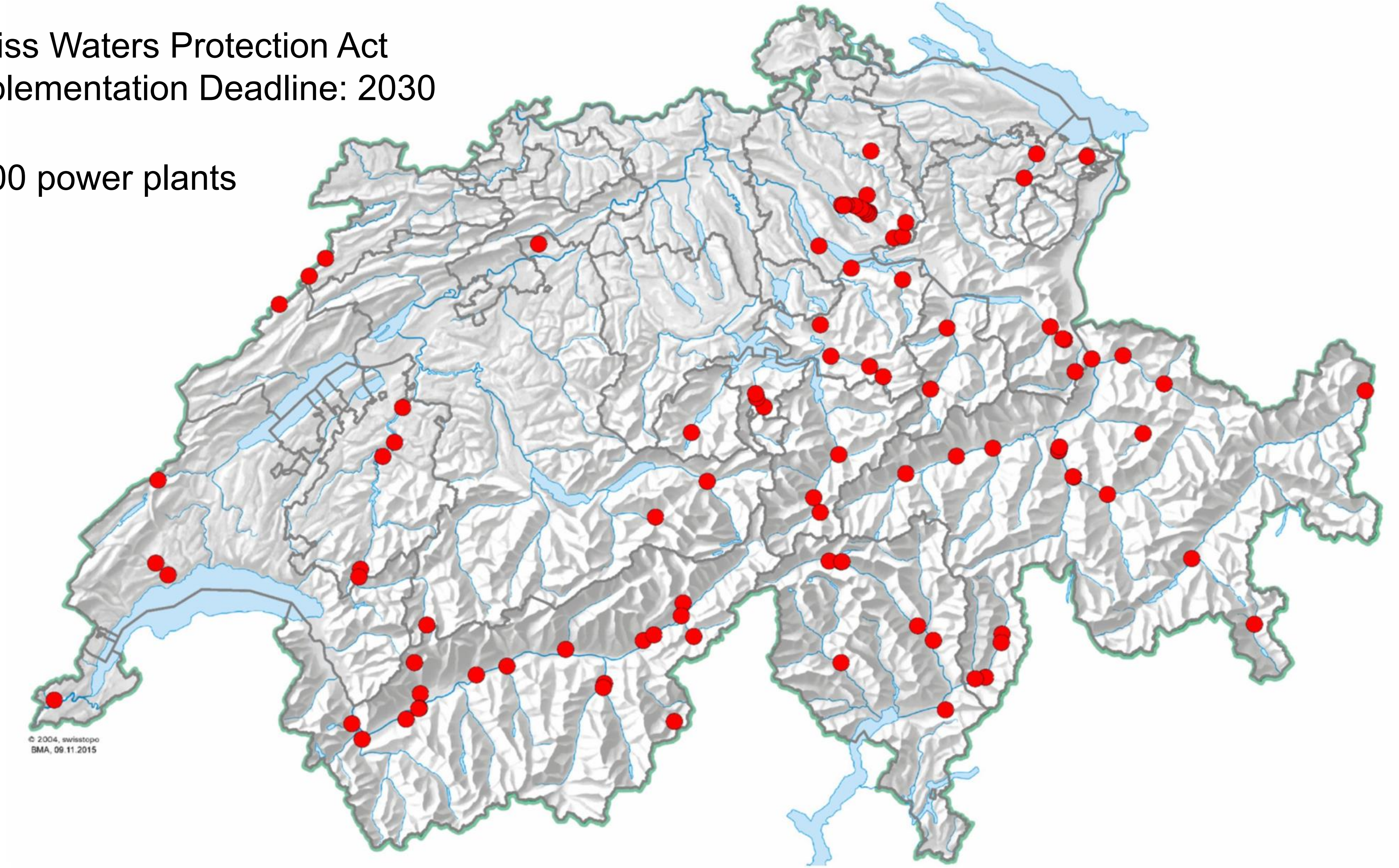



[Wikimedia Commons / Jérémy Toma]

# Hydropeaking Remediation of Storage Hydropower in CH

Swiss Waters Protection Act
Implementation Deadline: 2030

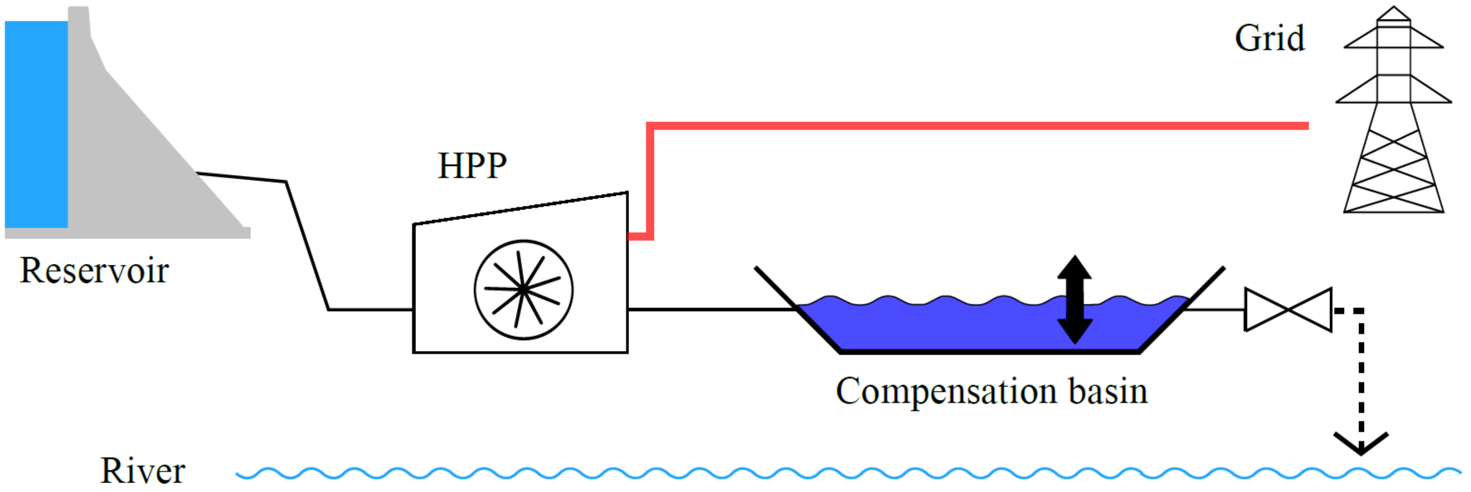
~100 power plants



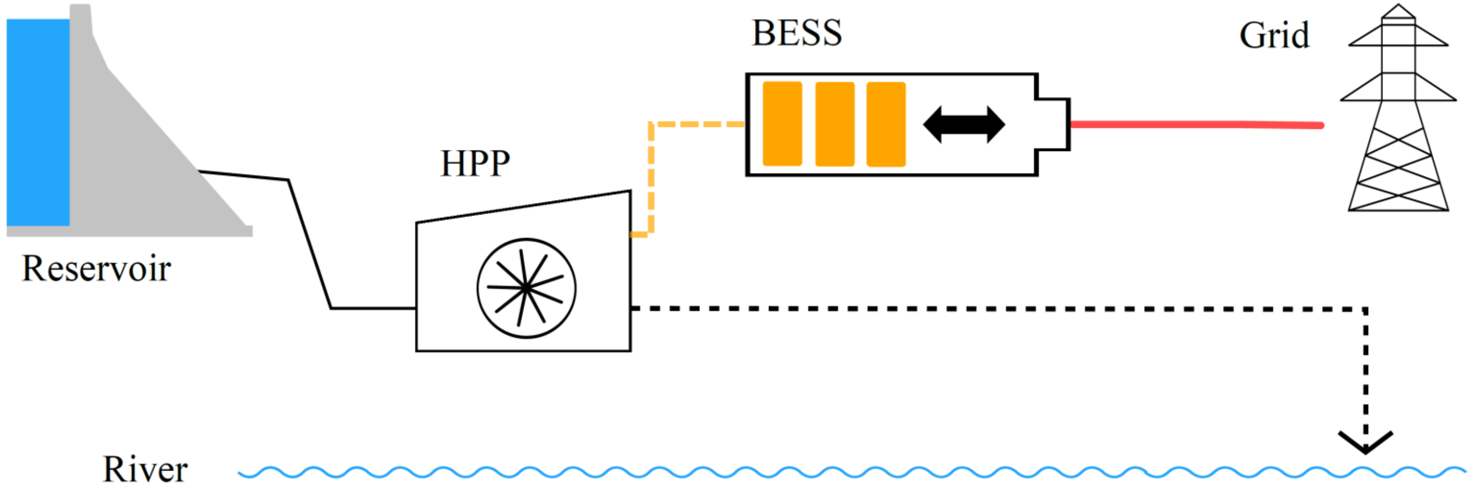

[ESA / Copernicus Sentinel / FOEN]

# Hybridization with Batteries – Hydropeaking Mitigation

Compensation Basin:




Battery Energy Storage System (BESS):



# Hybridization with Batteries – Technology

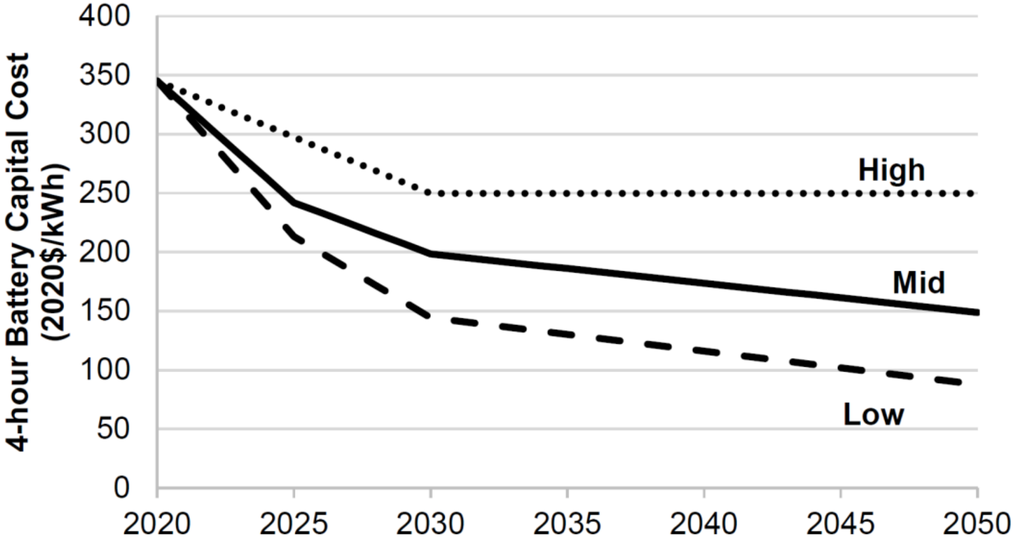
[MW Storage]

- Fast ramping capabilities
- Ancillary services
- Power arbitrage
- Decreasing costs (second-life)

Battery Energy Storage System (BESS)

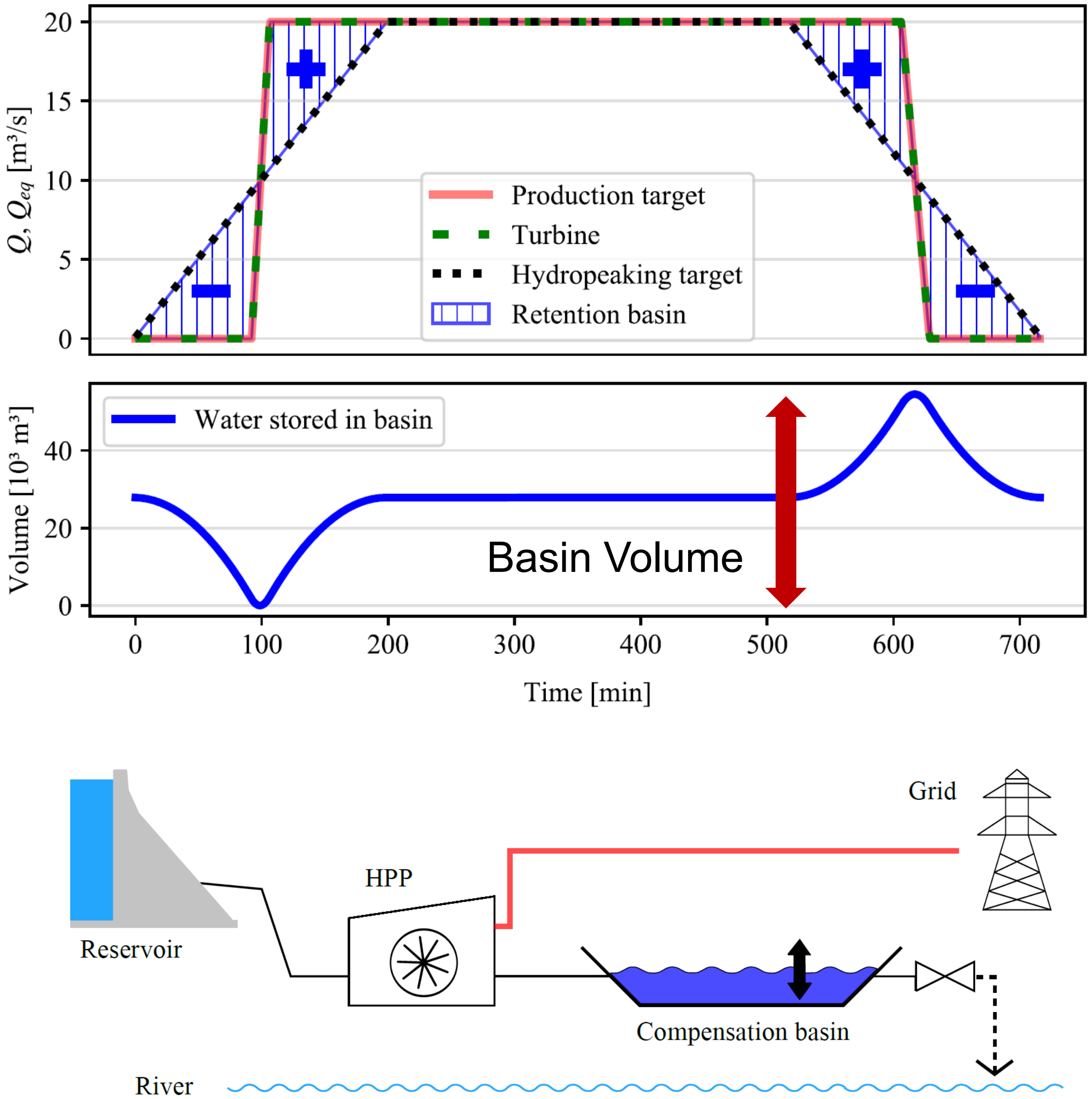
Largest BESS CH: Ingenbohl SZ
Power capacity: 20 MW
Energy capacity: 18 MWh

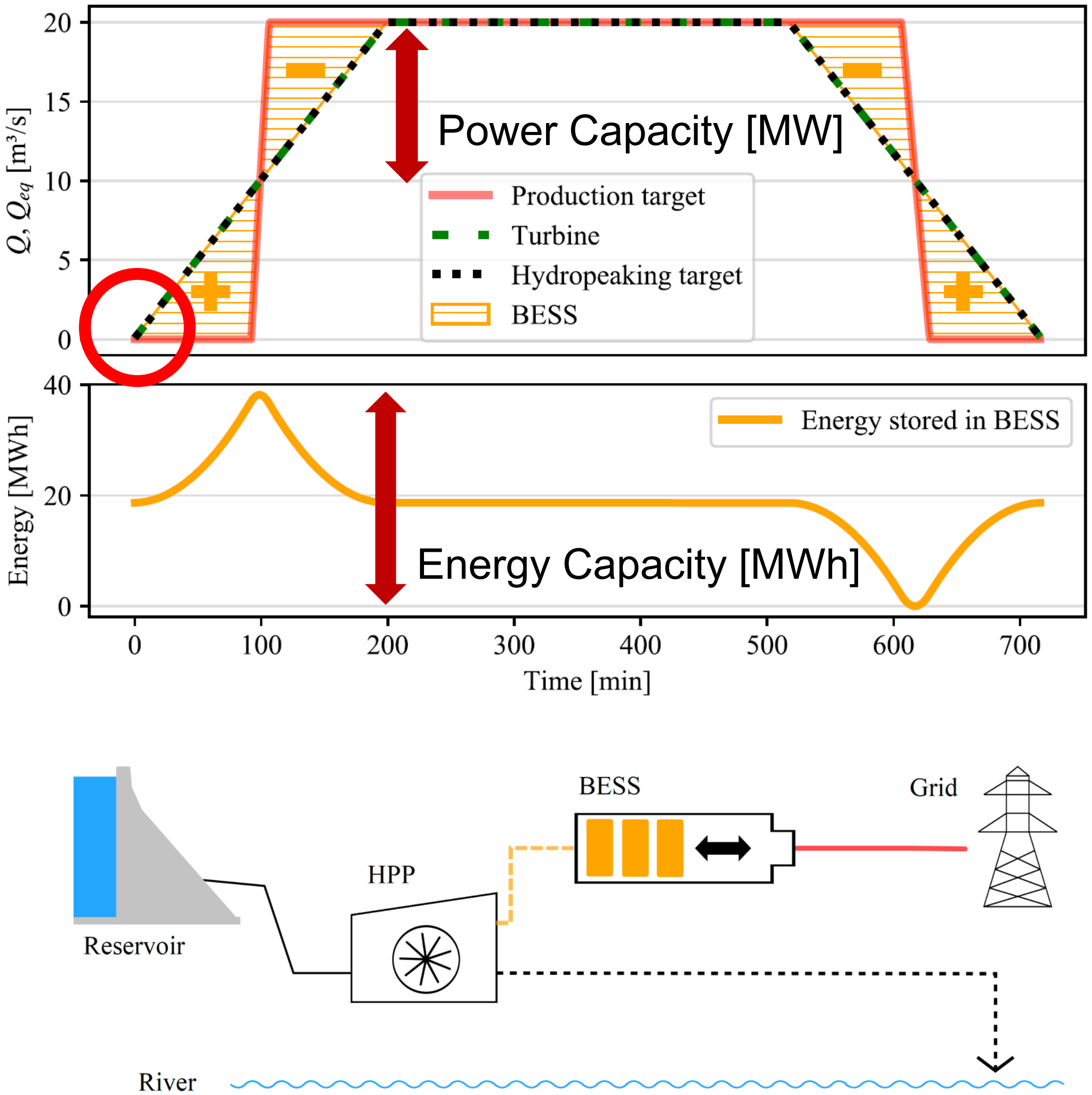
Largest BESS Europe: Alfeld/Leine (DE) (approved)
Power/Energy: 137.5 MW / 275 MWh



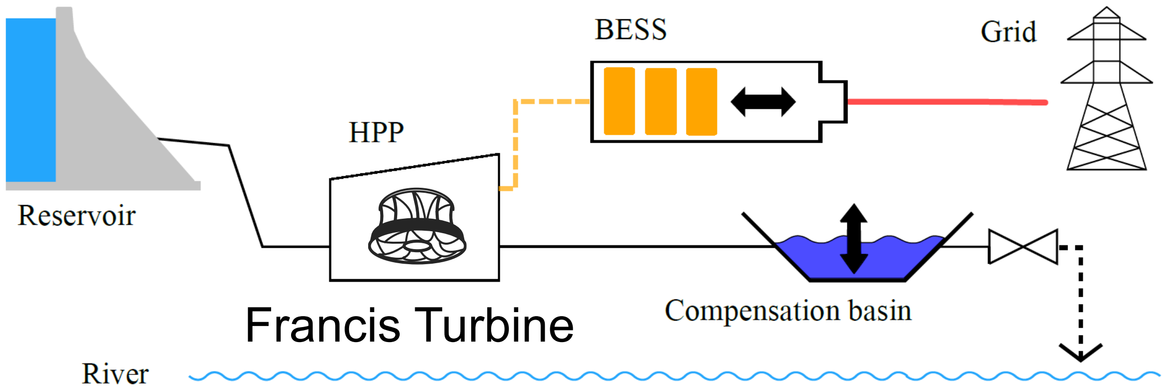

[NREL]

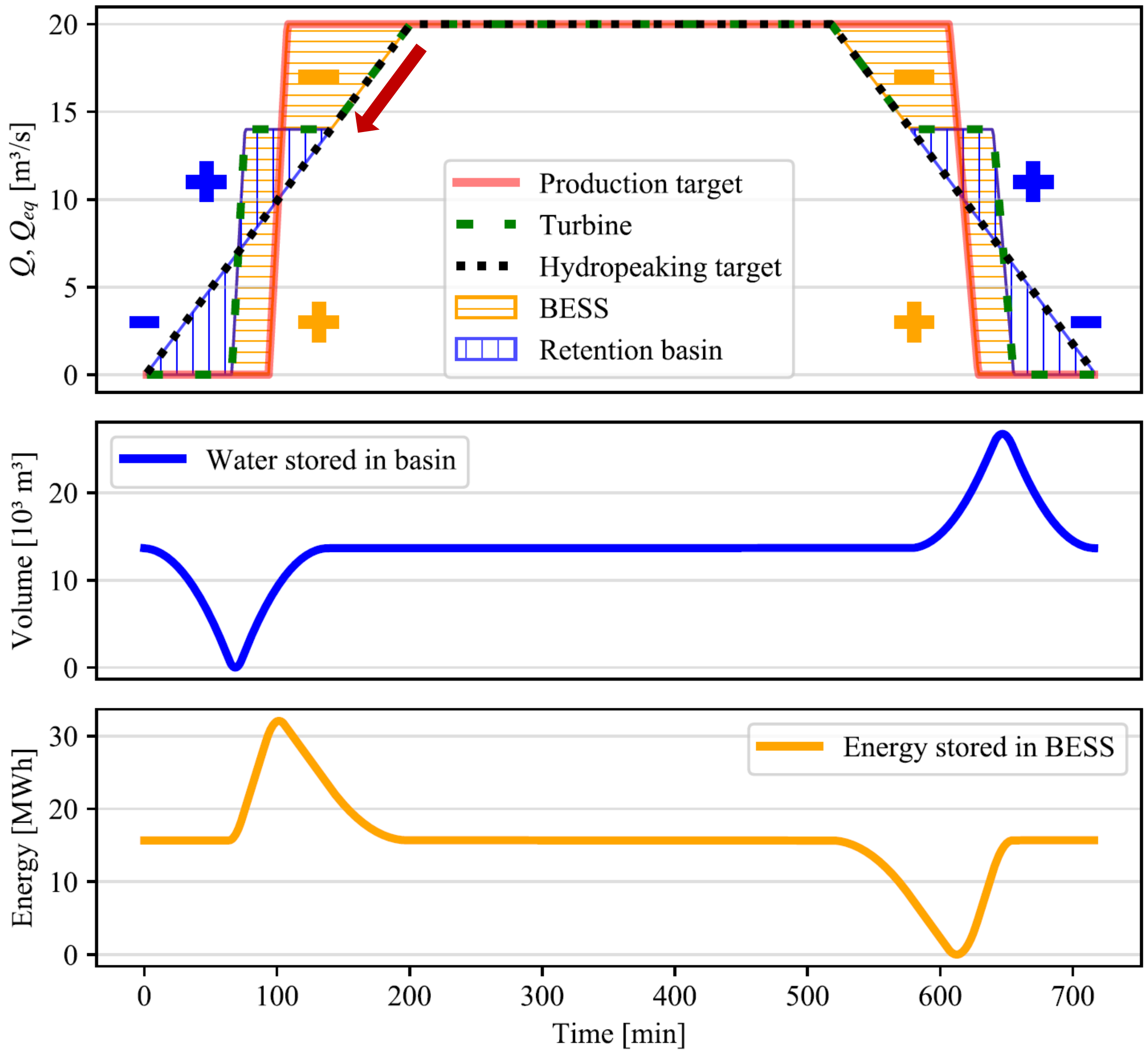
# Hydropeaking Mitigation – Operation



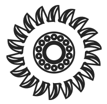



# Hybrid Basin-BESS System

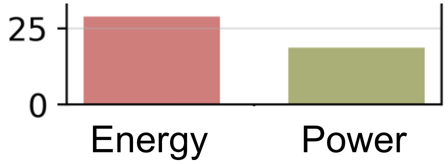


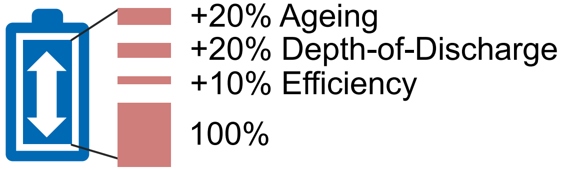




Turbine with better partial load behavior (e.g. Pelton)
→ basin volume decreases further
→ BESS energy capacity increases

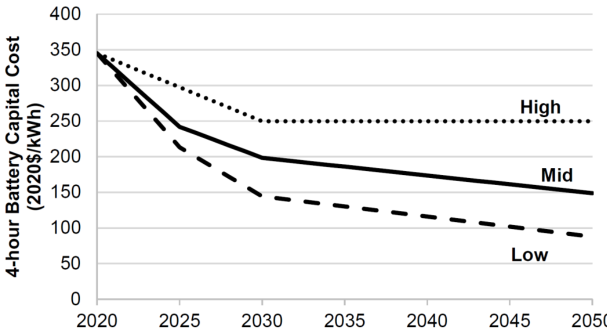


# Case Study – Cost Estimation




3 Battery Cost Scenarios (NREL):
Low, Middle, High



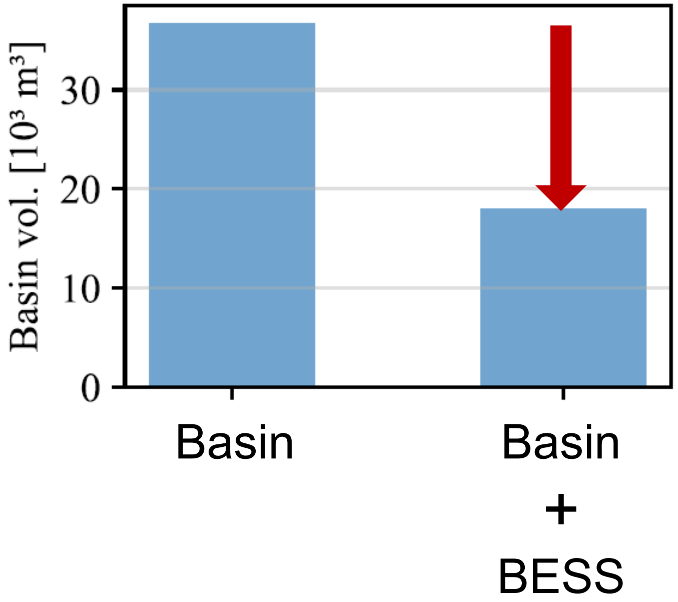

Assessment Period:
from 2030, 40 years

Battery Lifetime:
10, 15 years


Interest Rate: 3% & 5%

## ***E**quivalent **P**rice*

$$EP\ [\text{CHF/m}^3] = \frac{\text{BESS Costs [CHF]}}{\text{Volume Reduction [m}^3\text{]}}$$

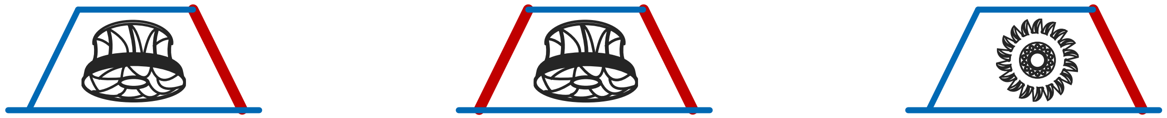


# Case Study – BESS Size, Volume Reduction, & Equivalent Price

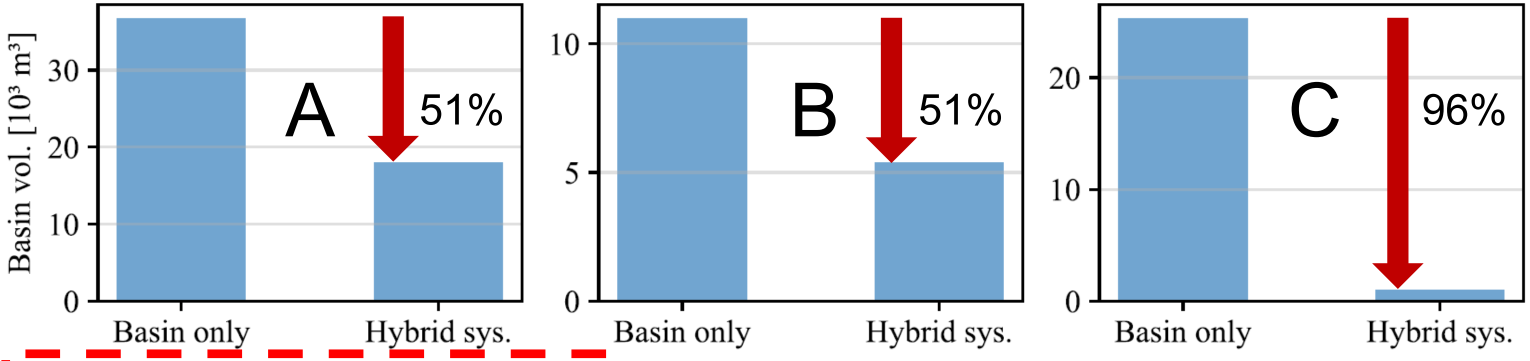
| | | | |
|---|---|---|---|
| *EEV* ≈ | 0.35 kWh/m³ | 0.86 kWh/m³ | 2.35 kWh/m³ |
| *Q* ≈ | 60 m³/s | 20 m³/s | 20 m³/s |
| *P* ≈ | 90 MW | 60 MW | 190 MW |
| $P_{BESS}$ ≈ | 18 MW | 42 MW | 51 MW |
| $E_{BESS}$ ≈ | 17 MWh | 13 MWh | 94 MWh |

*EEV*: ***E***nergy ***E***quivalence ***V***alue

Environmental Constraints:



Volume Reduction:




| **Price** | **Caverns: 500…800 CHF/m³** | ***Equivalent Price*** | |
|---|---|---|---|
| **Low** | 350…500 CHF/m³ | 2100…3000 CHF/m³ | 1100…1500 CHF/m³ |
| **Middle** | 500…800 CHF/m³ | 3500…5000 CHF/m³ | 1500…2500 CHF/m³ |
| **High** | 700…1000 CHF/m³ | 3500…5600 CHF/m³ | 2000…3000 CHF/m³ |

# Conclusions

- Battery Energy Storage Systems (BESS) may contribute to the mitigation of hydropeaking downstream of storage hydropower plants as part of a hybrid solution;
- Key trends in Switzerland and Europe (incl. energy transition, hydropower rehabilitation, concession renewal) and declining BESS costs might expedite the hybridization of (storage) hydropower;
- Depending on environmental constraints, operation modes, and energy equivalence values, BESS can already be competitive (additional services allow for further cost reduction);
- Additional R&D efforts are needed to validate and demonstrate the hybridization of high-head hydropower (→ recently started STORE-Project)

Robert Boes
boes@vaw.baug.ethz.ch

ETH Zürich
Laboratory of Hydraulics, Hydrology and Glaciology (VAW)
Hönggerbergring 26
8093 Zürich
Switzerland

www.vaw.ethz.ch

Reference:
Höfkes, G.F., Evers, F.M., Hohermuth, B., Boes, R.M. (2024). Hybrid hydropeaking mitigation at storage hydropower plants combining compensation basins with battery energy storage systems (BESS). *Journal of Energy Storage*. https://doi.org/10.1016/j.est.2024.111247