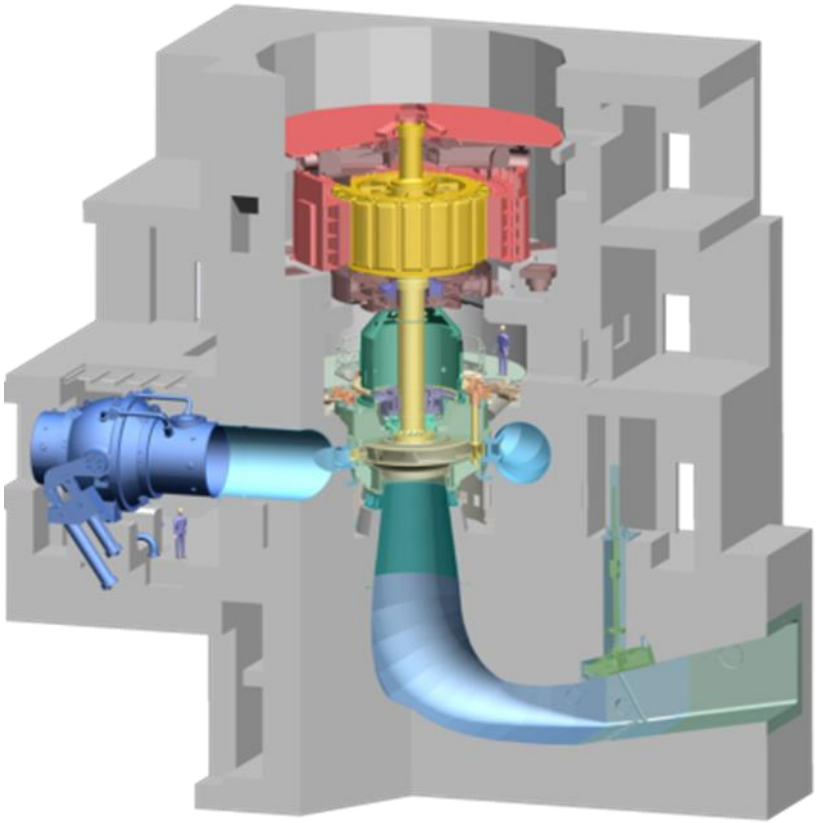


CARIBBEAN SUSTAINABLE ENERGY INDEPENDENCE

Pumped Storage as the Backbone of a Future 100%RE Power System for Barbados

Christian Stoebich / 11.11.2016

Agenda

- Introduction
- General Aspects of Pumped Storage
- Pumped Storage Concept Barbados
- References
- Conclusion

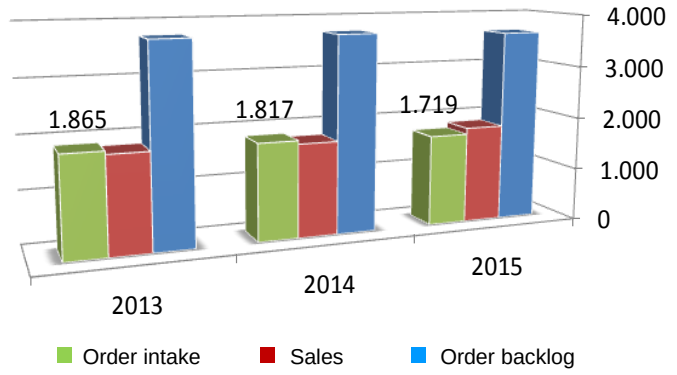
ANDRITZ Hydro

Introduction

ANDRITZ HYDRO					
Central Function					
	Large Hydro	Compact Hydro	Service & Rehab	Pumps	Turbo Generator

ANDRITZ HYDRO FIGURES 2015

	Unit	2015
Order intake	MEUR	1,718.7
Order backlog	MEUR	3,640.9
Sales	MEUR	1,834.8
EBITA	MEUR	145.3
Employees (without apprentices)		8,230



A global supplier of electro-mechanical systems and services (“from water-to-wire") for hydropower plants and a leader in the world market for hydraulic power generation.

ANDRITZ Hydro

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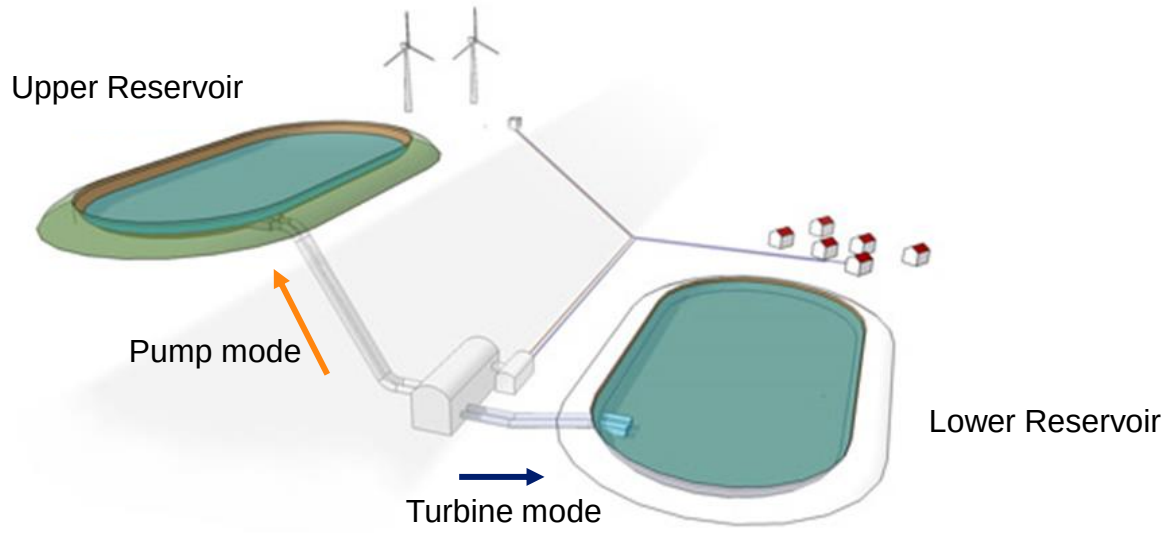
Basic Pumped Storage Concept

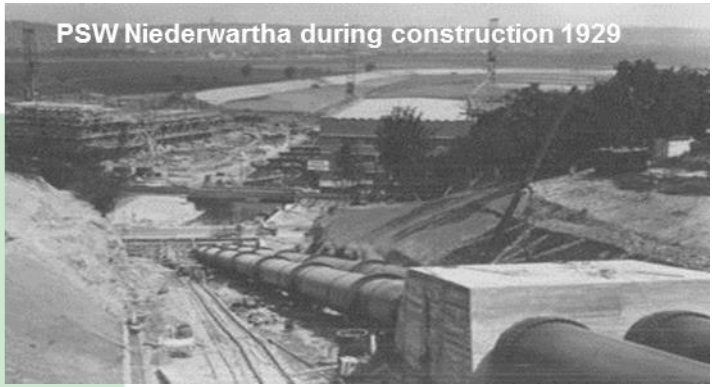
Pumped storage facility is made by two water basins, connected by a pressure pipe, with the water running through a pump-turbine rotating motor-generator

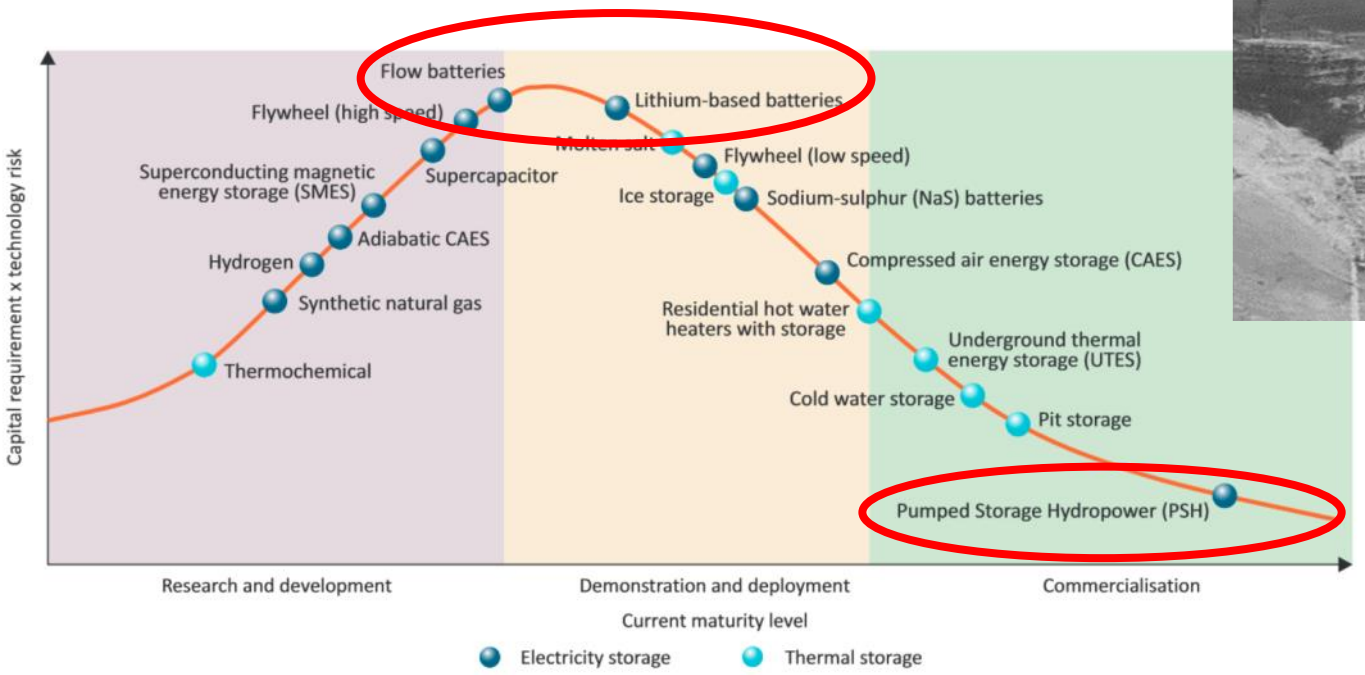


Storing potential energy by pumping the water from the lower basin to an upper one and using that energy by releasing the water back when required

ANDRITZ Hydro

Proven Mature Technology





Source: Decourt, B. and R. Debarre (2013), "Electricity storage", *Factbook*, Schlumberger Business Consulting Energy Institute, Paris, France and Paksoy, H. (2013), "Thermal Energy Storage Today" presented at the IEA Energy Storage Technology Roadmap Stakeholder Engagement Workshop, Paris, France, 14 February.

World Energy Council 2015:

" 99% of world's operational electricity storage is in hydropower (pump storage)"

IEC 2016:

"PSP is a significantly cheaper energy storage alternative compares to batteries, answering all national grid dynamic benefits needs "

Pumped Storage vs Batteries

LIFE TIME

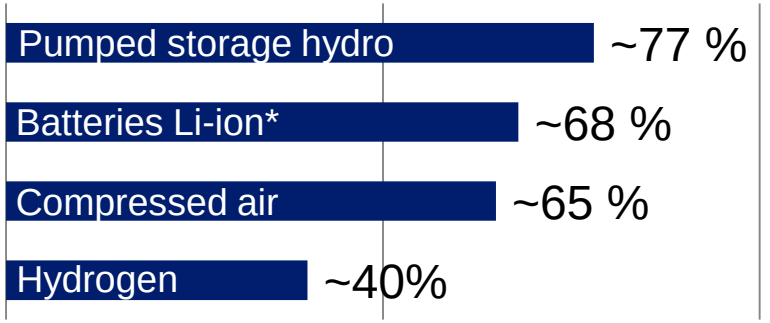
PSP BAT

> **50** years vs. ~**15** years

*Batteries Lifetime is 11-15 years**
Batteries storage capacity decreases substantially after 3 years

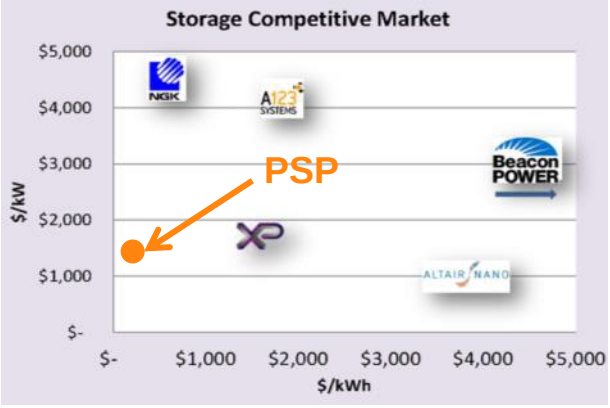
* According to NREL Predictive Models of Li-ion Battery Lifetime

TECHNOLOGY



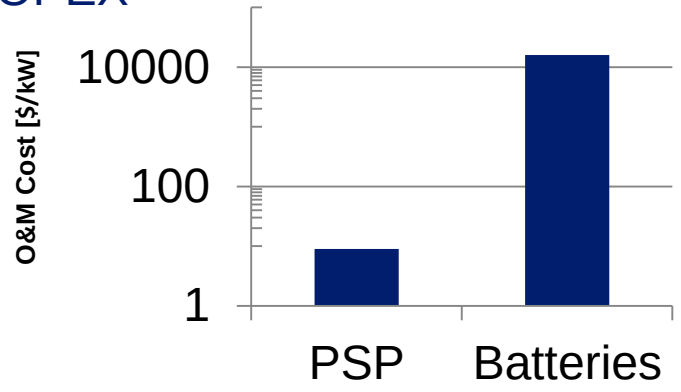
* Average Efficiency, which declines over the years for Batteries

CAPEX



According to EPRI Energy Storage Project A

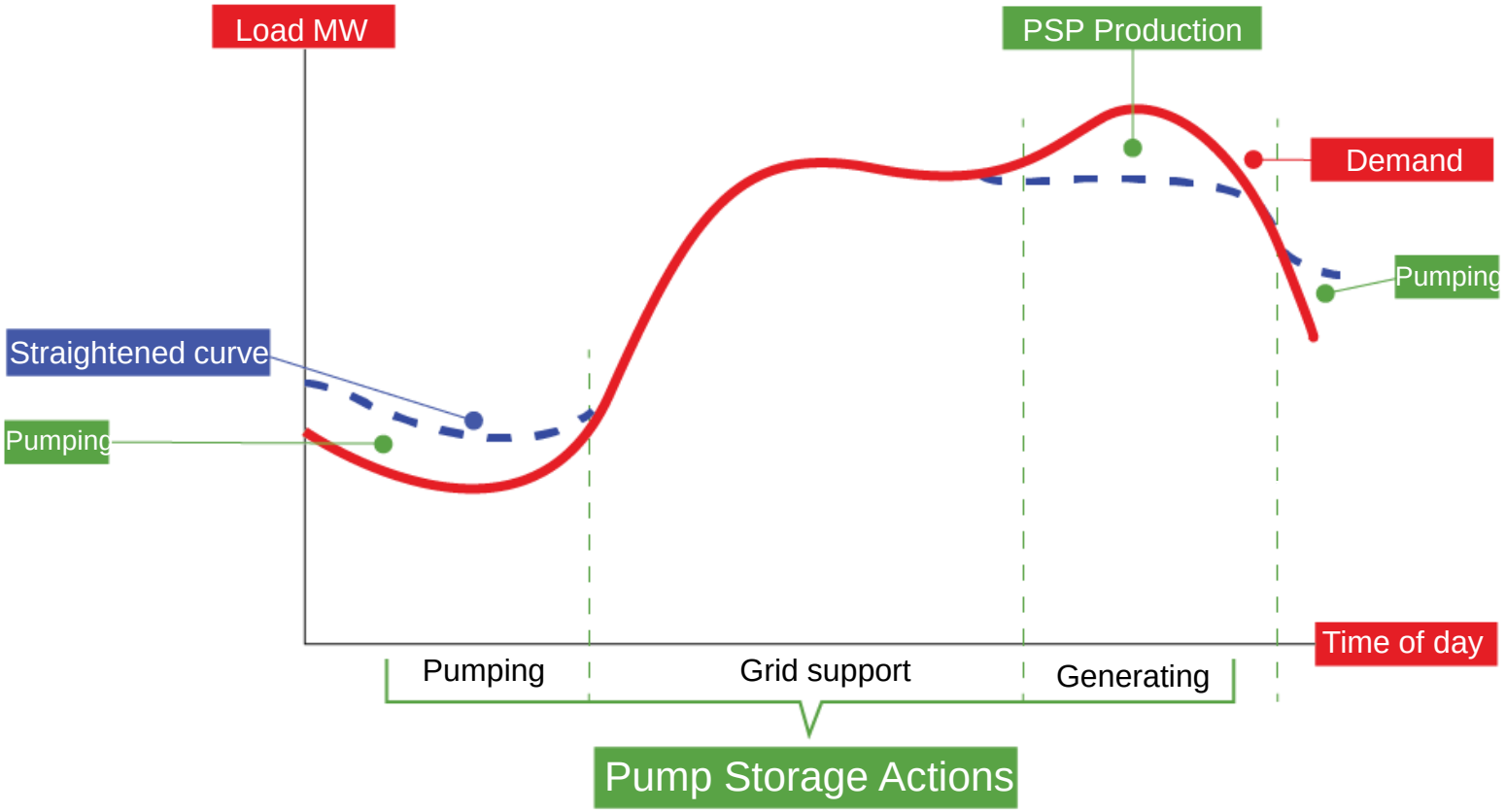
OPEX



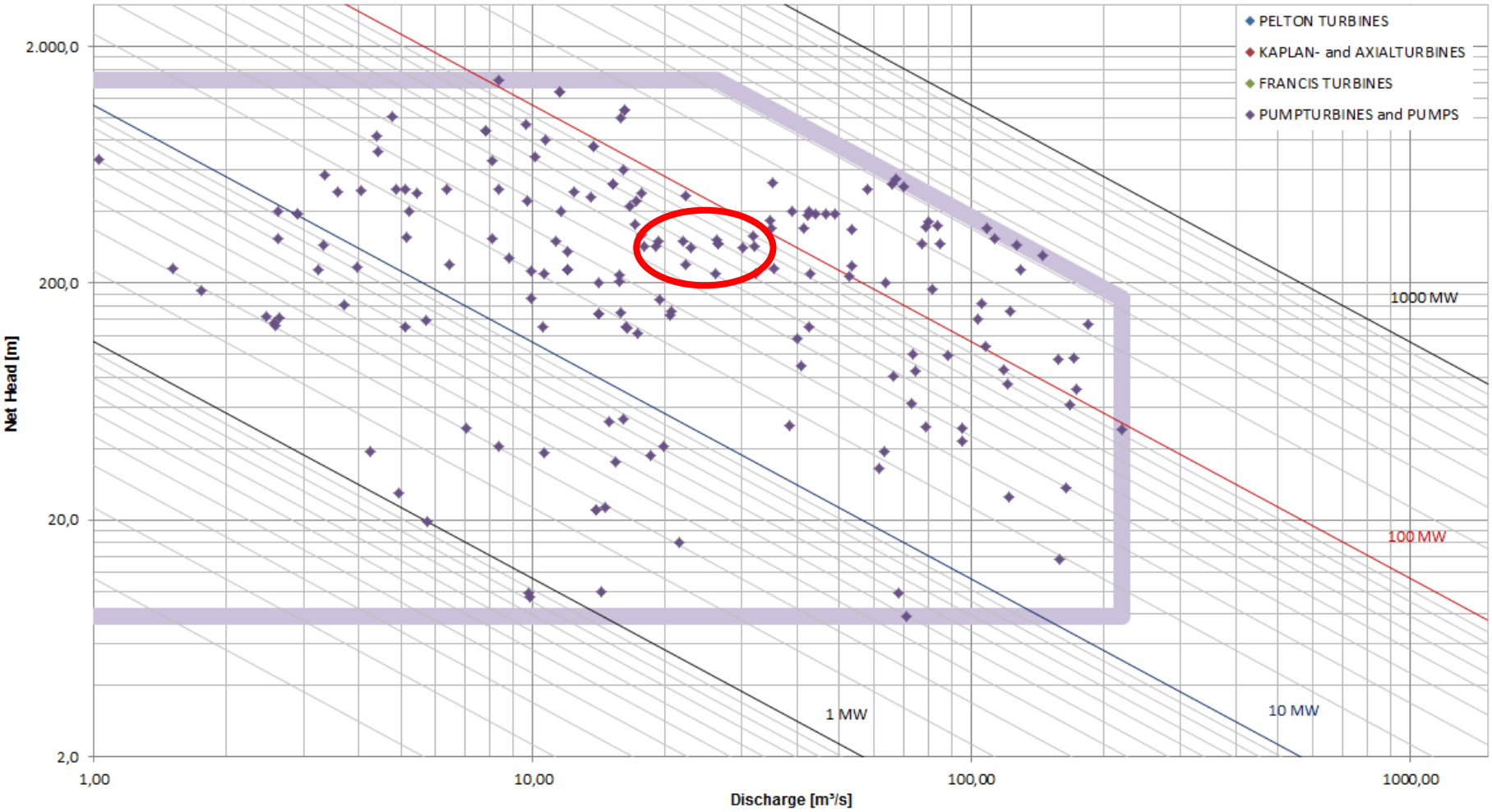
According to Energy Storage Screening Study For Integrating Variable Energy Resources within the PacifiCorp System July 9, 2014

Interaction in the system

Dynamic benefits, storage of renewable energies and savings of fuels are valid 24/7



Pumped Storage Reference Base



ANDRITZ Hydro

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ANDRITZ Hydro

Preliminary Concepts

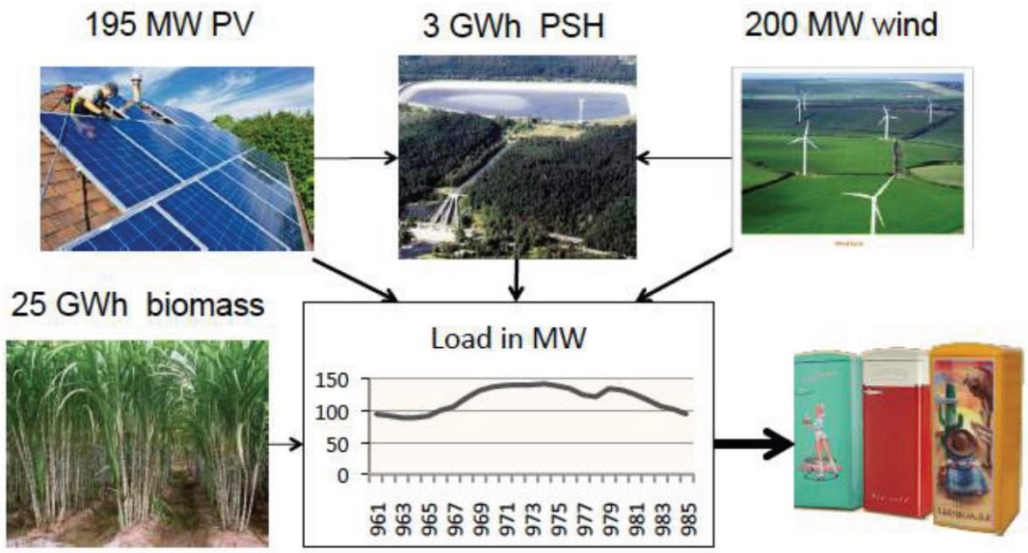
Basic Data:

- Available Head Range 240 – 250 m
- Generation Capacity 169 MW
- Pump Capacity 240 MW

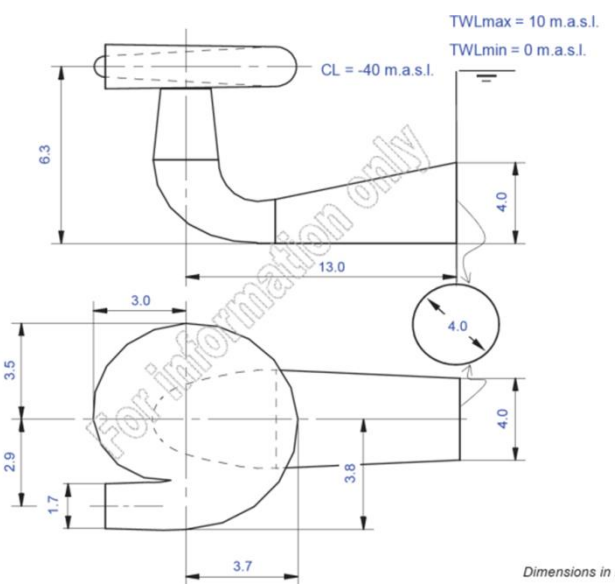
The size of the reservoir is depending basically on
- installed power
- hours of turbine operation / day
- operation regime (daily peaking, weekly storage?)
- available head range
- natural inflow (if any)

Possible Concepts:

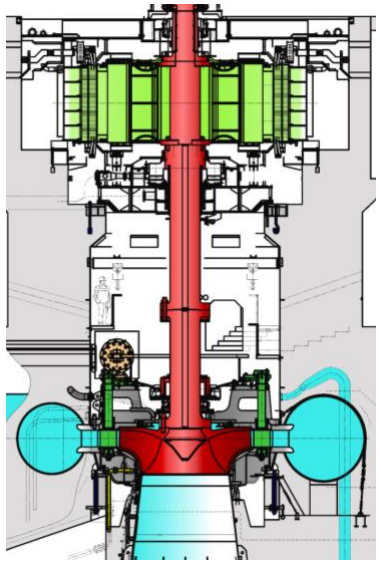
- Base Concept: Reversible Pump-turbines (fixed or variable speed): e.g. 3 x 80 MW
- Alternative: Ternary Units (split pump and turbine)



Source: Overall System - Prof. Dr. Olav Hohmeyer (2014)



Dimensions in meters



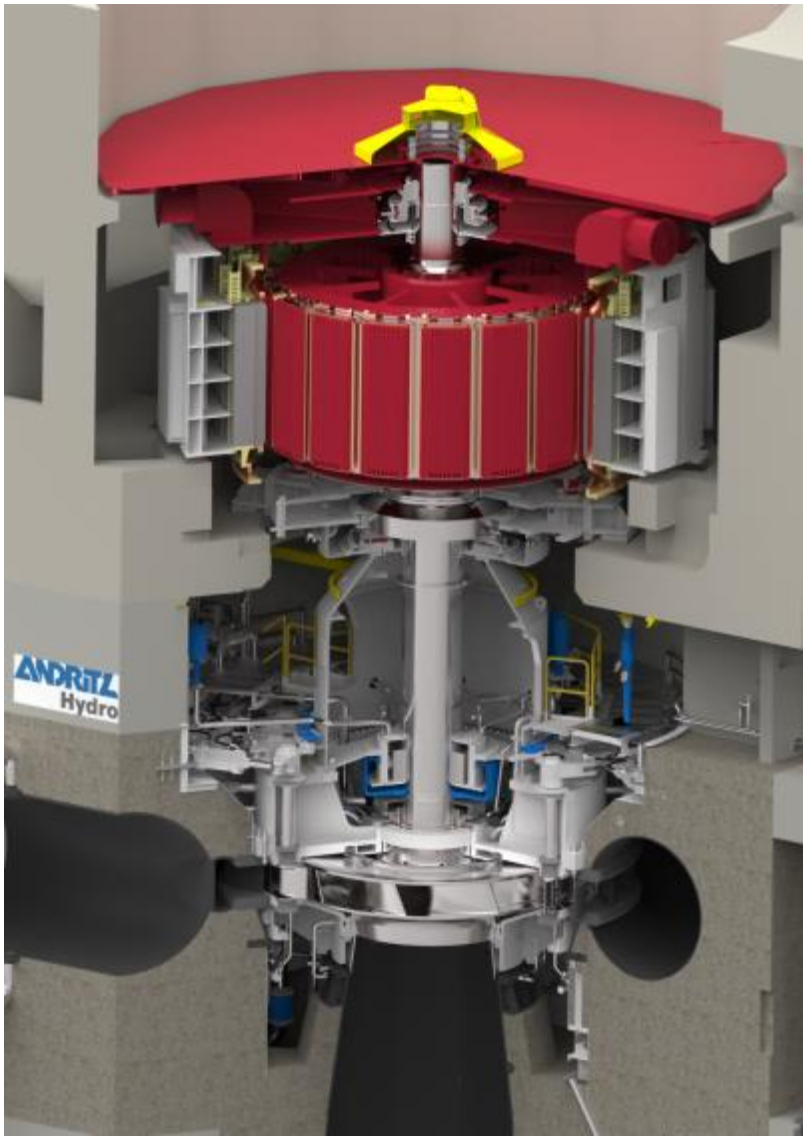
ANDRITZ Hydro

Preliminary Concepts

Reversible pump turbines – fixed speed

- **Advantage:**
  - Compact powerhouse
  - Most cost effective solution
- **Disadvantage:**
  - Longer mode change
    Turbine ←→ Pump
  - Start in pump mode requires high power of water depression

Not Recommended



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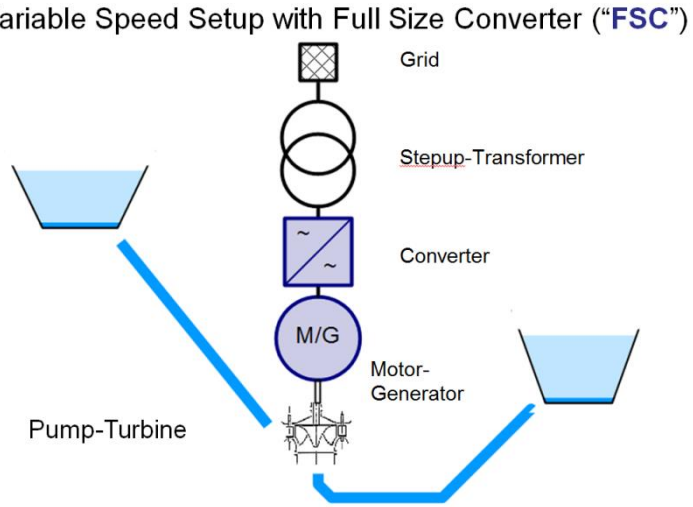
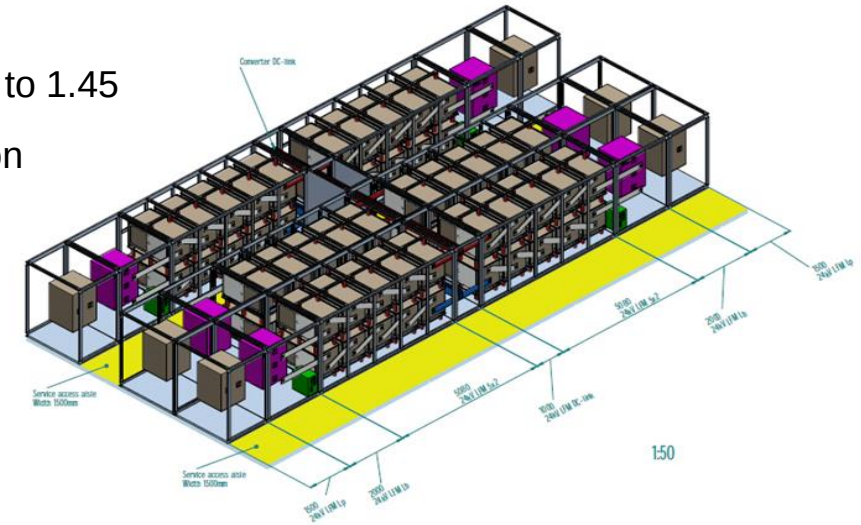
Preliminary Concepts

Reversible pump turbines with variable speed



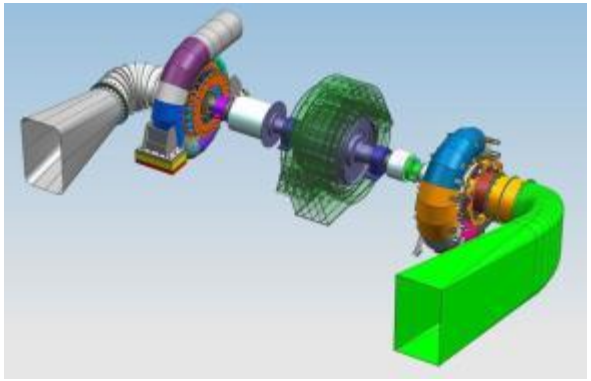
- **Advantage:**
  - Optimal adjustment to head variations
  - Increased efficiency in turbine mode (shifting of operating point)
  - Continuous variation of output with hydraulic limitation in pump operation
  - Increasing of lifetime by reduction of vibrations
  - Extended range of operation (head)
    - ratio max./min. head for FIX speed approx. 1.25
    - ratio max./min. head for VARIABLE speed approx. 1.25 to 1.45
    - faster mode change in comparison to fixed speed solution
      Turbine ←→ Pump
- **Disadvantage:**
  - Higher cost
  - Additional space for the converter



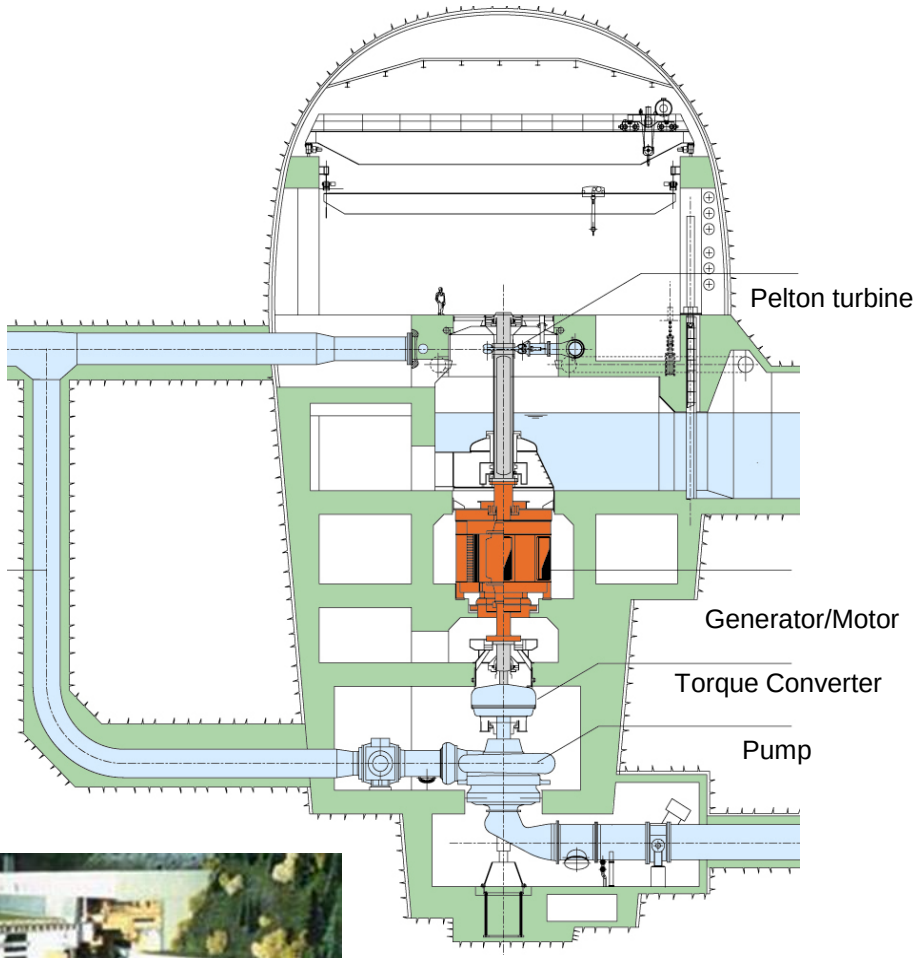
Hydro

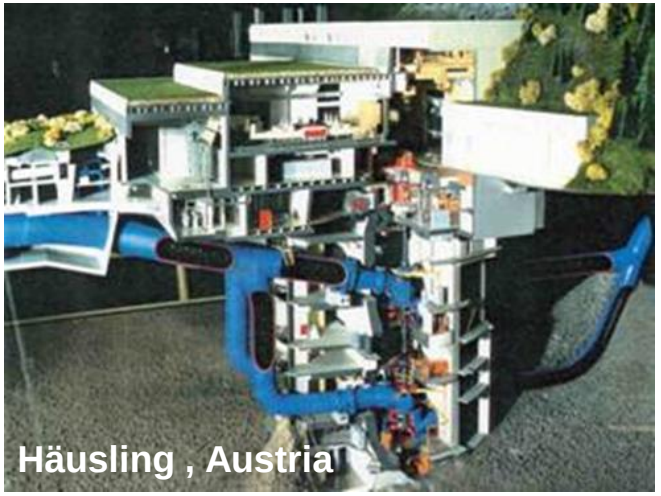
Preliminary Concepts

Ternary units



- **Advantage:**
  - Fast mode change
    Turbine ←→ Pump
  - Start to pump mode in water
  - Optimized Turbine- and Pump efficiency
  - Possibility of direct hydraulic short-circuit
    (Regulating energy)
- **Disadvantage:**
  - Increased Investment
  - Additional space requirement
  - Additional valves





ANDRITZ Hydro

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ANDRITZ Hydro

Goldisthal, Germany

Customer:

- Vattenfall

Main Equipment:

- 4x265 MW single stage reversible Pumpturbines, 2x340 MVA and 2x331 MVA Motorgenerators, AC Excitation und Starting - SFC
- Net Head 302 m
- 300..346 rpm and 333 rpm

Project Highlights

- Each two sets of synchronous and double fed asynchronous M/G
- Central location in the UCTE gri

Since 2003 successful in operation

First speed variable Pumped Storage Plant in Europe

ANDRITZ Hydro

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Pumped storage …

PSP is the proven and stable large-scale energy storage technology

- ☑ Cheaper for installed kW
- ☑ Cheaper for kWh
- ☑ Cheaper total CAPEX and OPEX
- ☑ Much longer Lifetime
- ☑ Environmental friendly
- ☑ Smaller footprint

Answers grid instability issues resulting from increasing volume of renewable energies !

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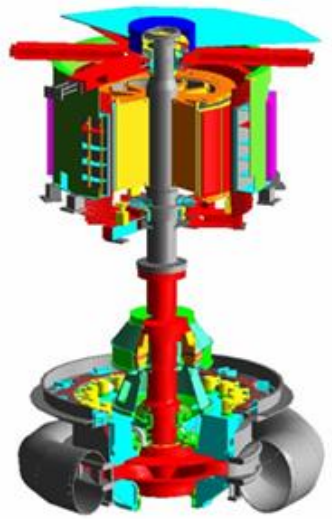
Pumped storage …



- has special importance regarding the entire energy system
- provides balancing and reserve energy and increases grid stability
- becomes more important by adding volatile wind and solar power
- contributes to mitigate the global climate change challenges
- schemes take advantage of the progresses made in the field of hydraulics, generator, power electronics and automation technology in recent years

Variable speed ….

- amplifies the effects of conventional solutions
- increases flexibility to react on market needs
- has the potential to maximize economical viability

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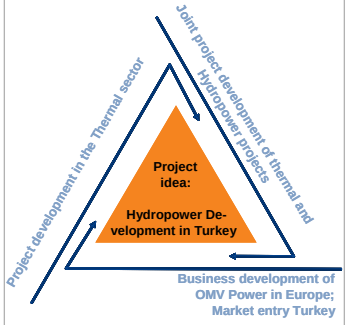
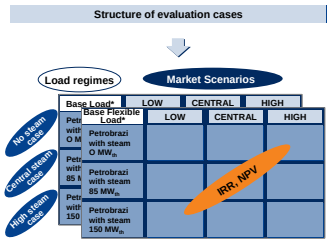
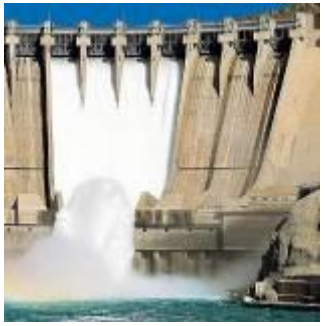
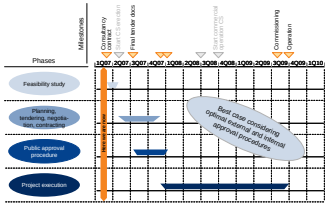
Way forward …

Policies, Regulatory Framework, Master Plan

Review of Design – Conceptual Study	FEASIBILITY STUDY / ESIA	TENDER / FINAL DESIGN	PROJECT CONSTRUCTION
			
• Critical review of HP plants • Understand technical solution and options • Check on alternatives • Understand legal and institutional framework • Evaluate environmental impacts	• Elaboration of technical solution • Geological investigations • Market model & economic analysis • Risk assessment • Organisational issues • Evaluation	• Technical documents • Commercial documents • Contract Agreements • Permits & Licences • Financial Closure	• Project Management • Detailed Design • Manufacture, Construction • Commissioning • Implementation of EMP
3 months	6 -12 months Depending on geological investigations	6 – 12 months	24 – ? months

ANDRITZ Hydro

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