ALPHEUS

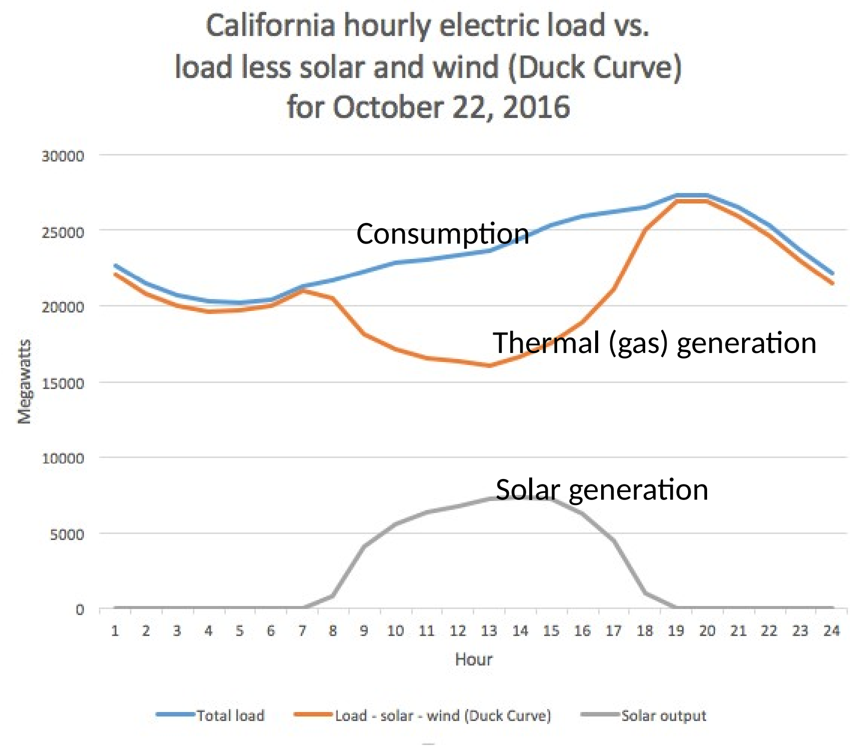
ALPHEUS: **A**ugmenting grid stability through **L**ow head **P**umped **H**ydro **E**nergy **U**tilization and **S**torage

Grid-scale pumped hydro storage for the low countries

The ALPEHUS project (https://alpheus-h2020.eu) has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 883553.

The renewable energy problem – the duck curve

- Intermittent electricity generation does not match consumption
- Grid scale energy storage needed
- Thermal (coal, oil, gas) plant generation can be adjusted to meet consumption, but renewables cannot

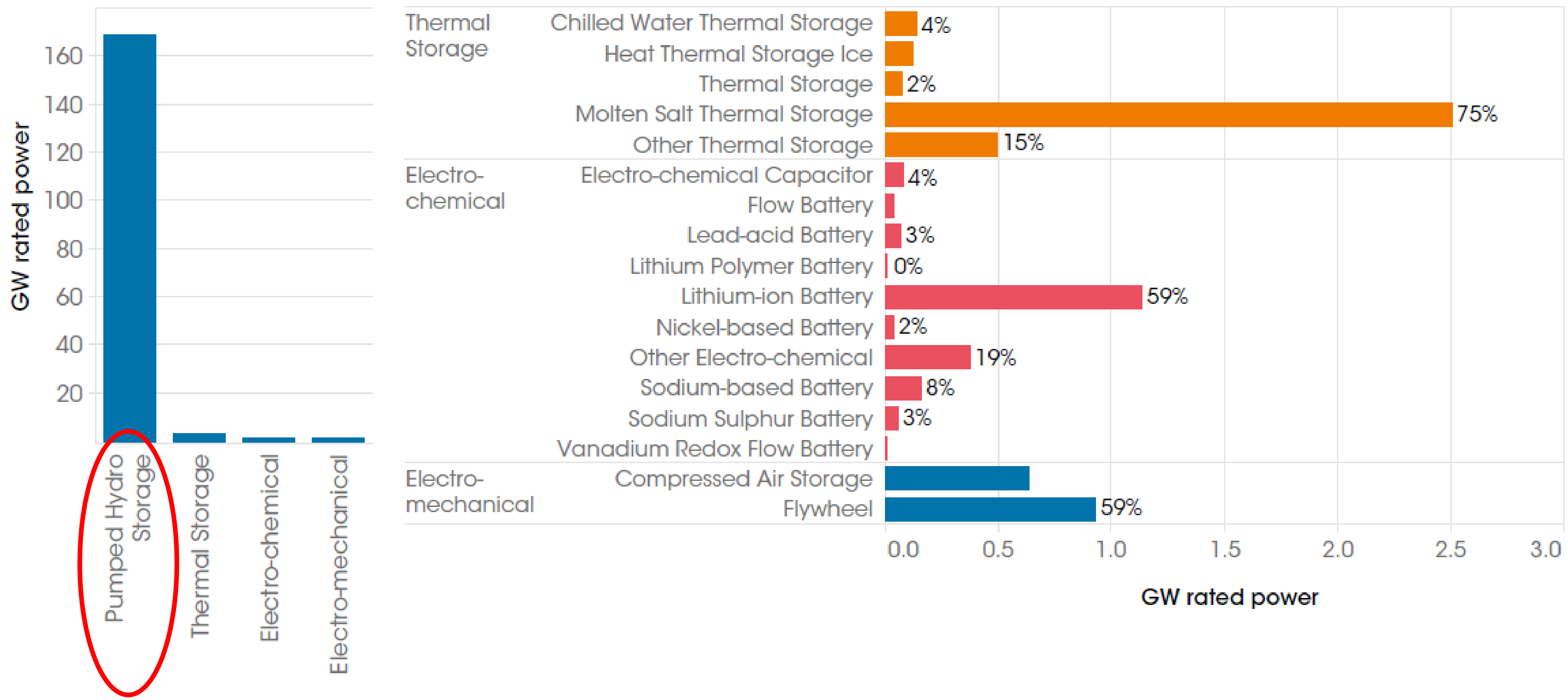


Wikipedia

Global energy storage

Pumped hydro is the world’s most widespread and utilized energy storage technology

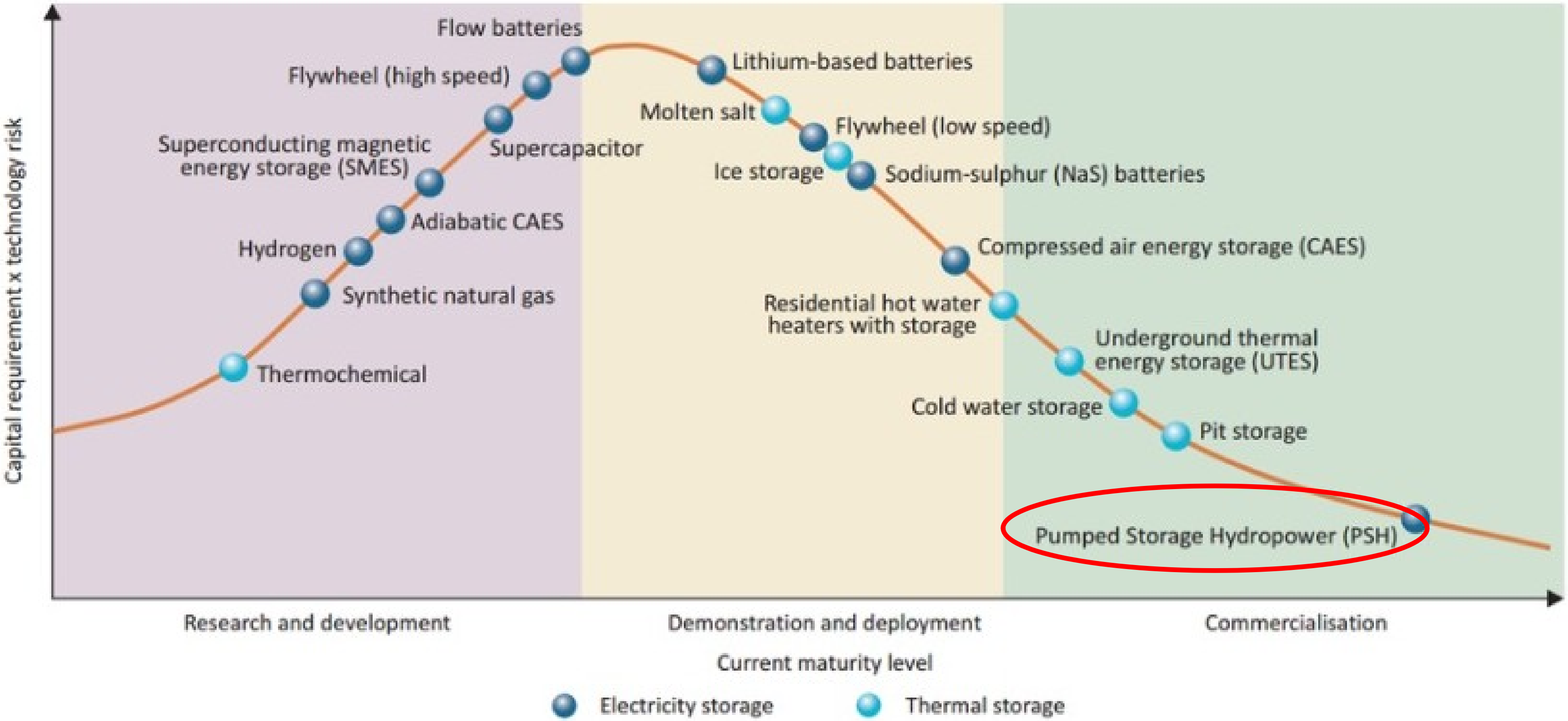
Figure ES8: Global operational electricity storage power capacity by technology, mid-2017



IRENA (2017)

Maturity of storage technologies

Pumped hydro is the world’s most mature energy storage technology



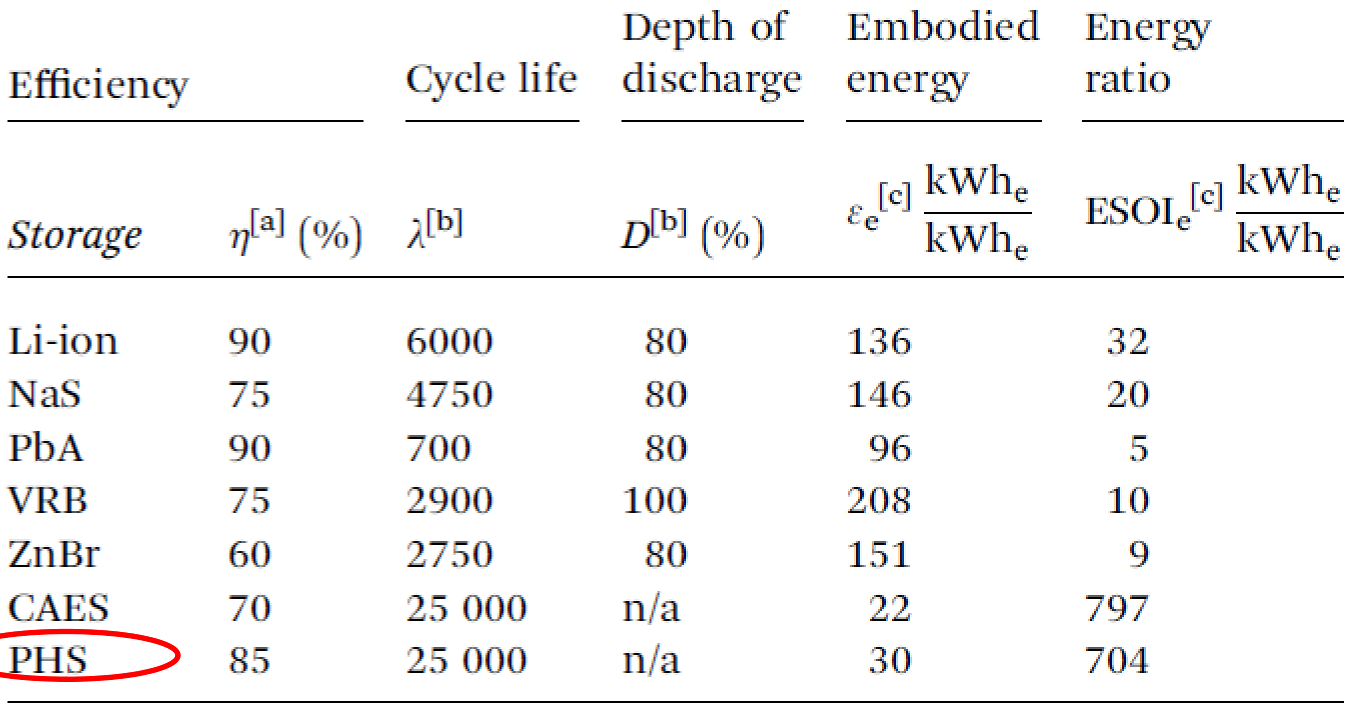
Source: Decourt, B. and R. Debarre (2013), “Electricity storage”, *Factbook*, Schlumberger Business Consulting Energy Institute, Paris, France and Paksoy, H. (2013), “Thermal Energy Storage Today” presented at the IEA Energy Storage Technology Roadmap Stakeholder Engagement Workshop, Paris, France, 14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

World Energy Council 2015: 99% of world’s operational electricity storage is in hydropower (pumped storage)

Energy Storage on Investment ESOI

Pumped hydro is among the world’s most efficient and environmentally friendly energy storage technologies

ESOI is the energy that can be stored over the lifetime of a technology, divided by the energy used to fabricate, maintain, and decommission the technology.



Efficiency		Cycle life	Depth of discharge	Embodied energy	Energy ratio
Storage	η[a] (%)	λ[b]	D[b] (%)	ε_e[c] $\frac{kWh_e}{kWh_e}$	$ESOI_e$[c] $\frac{kWh_e}{kWh_e}$
Li-ion	90	6000	80	136	32
NaS	75	4750	80	146	20
PbA	90	700	80	96	5
VRB	75	2900	100	208	10
ZnBr	60	2750	80	151	9
CAES	70	25 000	n/a	22	797
PHS	85	25 000	n/a	30	704

Barnhart et al. (2013)

Costs of energy storage technologies

Pumped hydro is among the world’s cheapest energy storage technologies

P. Nikolaidis, A. Poullikkas (2018)

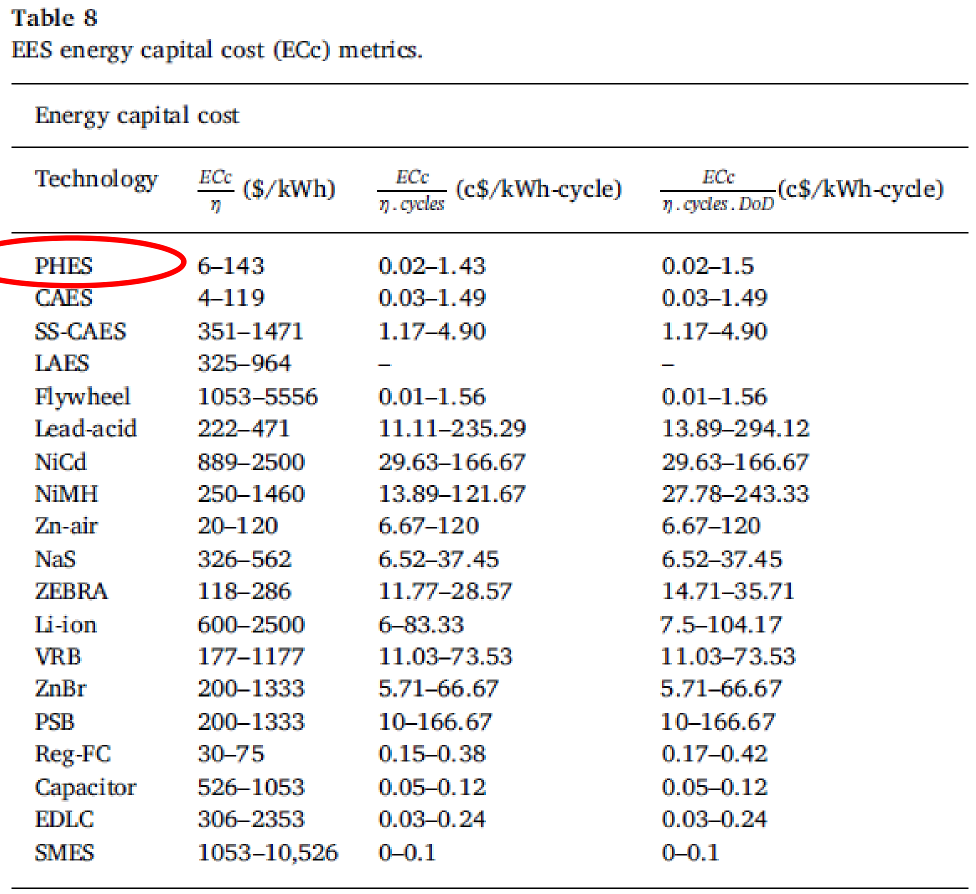
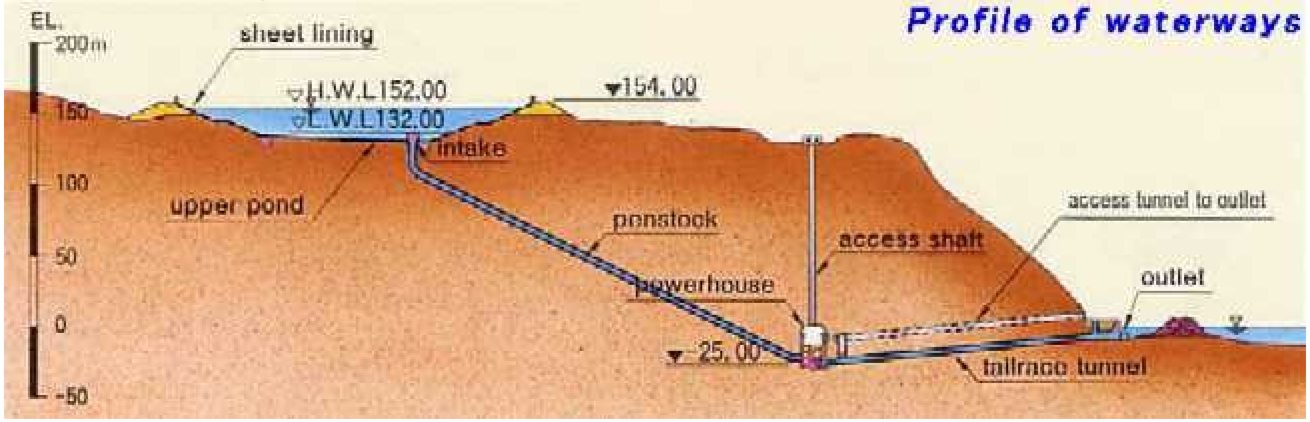


Table 8
EES energy capital cost (ECc) metrics.

Energy capital cost			
Technology	$\frac{ECc}{\eta}$ ($/kWh)	$\frac{ECc}{\eta\,.\,cycles}$ (c$/kWh-cycle)	$\frac{ECc}{\eta\,.\,cycles\,.\,DoD}$ (c$/kWh-cycle)
PHES	6–143	0.02–1.43	0.02–1.5
CAES	4–119	0.03–1.49	0.03–1.49
SS-CAES	351–1471	1.17–4.90	1.17–4.90
LAES	325–964	–	–
Flywheel	1053–5556	0.01–1.56	0.01–1.56
Lead-acid	222–471	11.11–235.29	13.89–294.12
NiCd	889–2500	29.63–166.67	29.63–166.67
NiMH	250–1460	13.89–121.67	27.78–243.33
Zn-air	20–120	6.67–120	6.67–120
NaS	326–562	6.52–37.45	6.52–37.45
ZEBRA	118–286	11.77–28.57	14.71–35.71
Li-ion	600–2500	6–83.33	7.5–104.17
VRB	177–1177	11.03–73.53	11.03–73.53
ZnBr	200–1333	5.71–66.67	5.71–66.67
PSB	200–1333	10–166.67	10–166.67
Reg-FC	30–75	0.15–0.38	0.17–0.42
Capacitor	526–1053	0.05–0.12	0.05–0.12
EDLC	306–2353	0.03–0.24	0.03–0.24
SMES	1053–10,526	0–0.1	0–0.1

High head (traditional) pumped hydro storage

Utilizes head topographic head difference (mountains) and Francis pump/turbines



Source: http://web.archive.org/web/20030430003158/http://www.jcold.or.jp/Eng/Seawater/Outline.htm

Source: http://seawaterpower.com/mp-sps.html

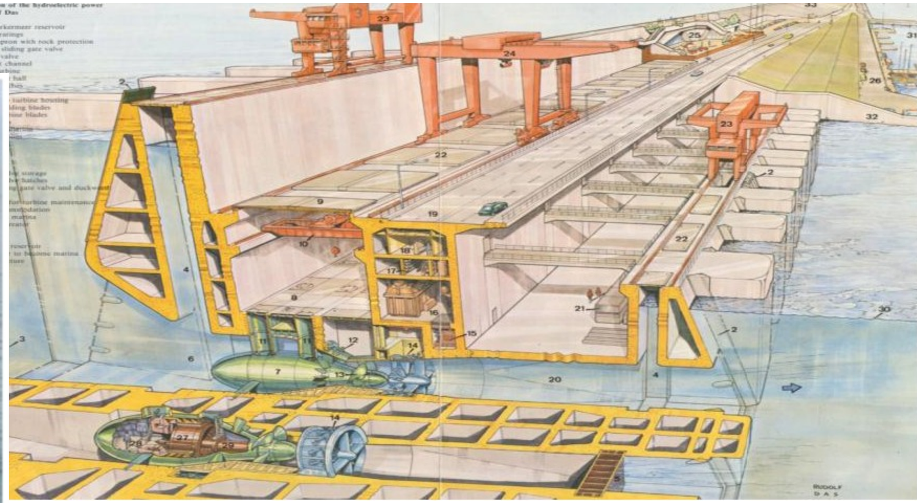
What happens if you have no mountains?
- The low countries

- The North Sea periphery (Netherlands, Belgium, northern France, Denmark, eastern England, German coast) have no natural topography
- Large scale grid stability currently relies on high voltage direct current (HVDC) cables, i.e., the NorNed cable, NordLink, North Sea Link, Skagerrak
- Cables sometimes fail (i.e., NorNed failed for 7 weeks in 2011), so local storage would increase grid flexibility and reliability

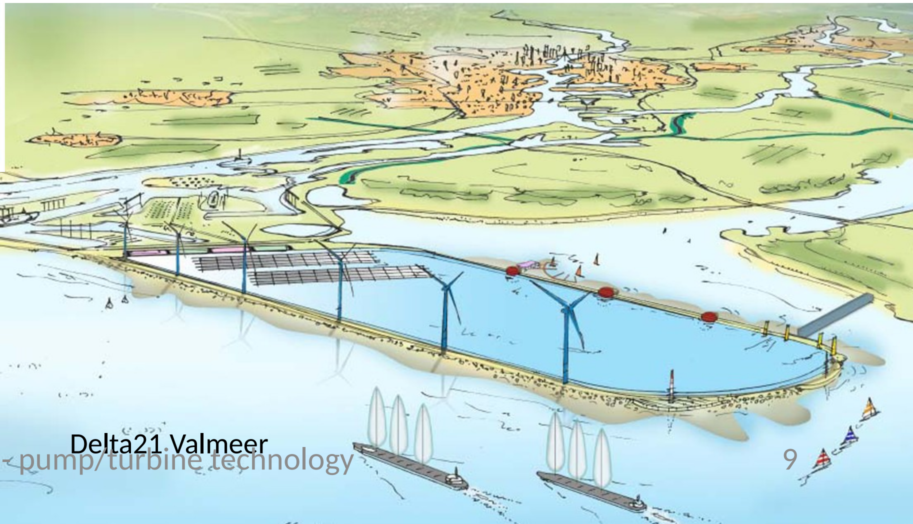
JRC (2015)

Low country ideas for pumped hydro storage

- Dike and/or caisson rings in the North Sea to create a pumped hydro storage basin



Artist impression ‘Valmeer’ by Robbert & Rudolf Das



Delta21 Valmeer

Problems with low head seawater pumped hydro

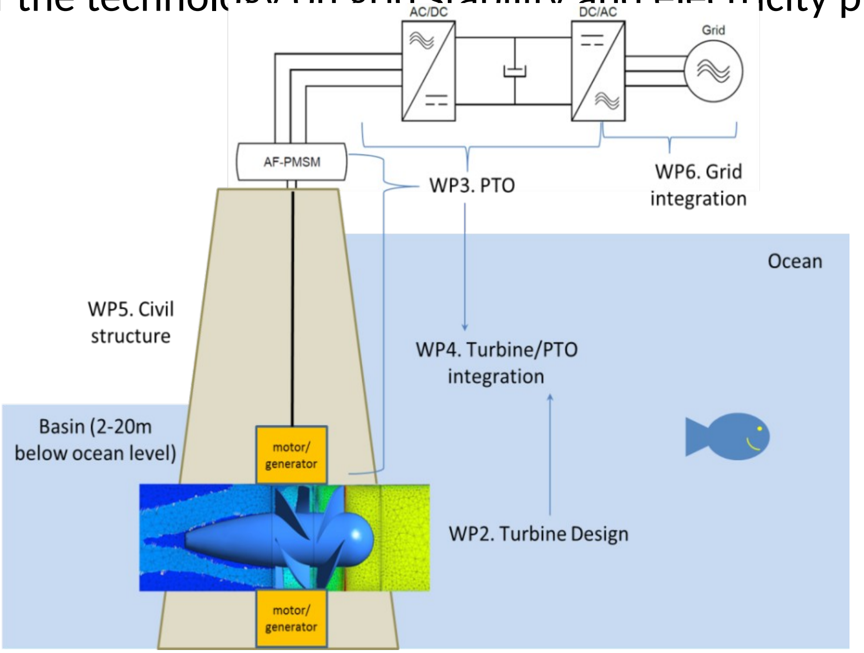
- High efficiency Francis reversible pump turbines (RPT’s) work for heads over ~20 m, but high efficiency axial RPT’s for lower heads have not yet been developed
- A power take off (PTO, or drivetrain) for low-head RPT’s subject to frequent and rapid reversal (switching between pump and turbine mode) has not yet been developed
- Dams (dikes) and powerhouses subject to rapid and frequent water level variations have not yet been designed or built
- The effect of local energy storage on the EU grid has not yet been assessed
- Measures to prevent or reduce fish mortality due to a low head pumped hydro storage facility have not yet been investigated

About ALPHEUS

- EU H2020 Research and Innovation Action
- €5 Million over 4 years (April 2020- March 2024)
- 11 European partners
- Coordinator is TU Delft Civil Engineering
- Objective is to develop conceptual designs for low head pumped hydro storage facilities:
  - Develop high efficiency low head reversible pump/turbine with ability to switch operating mode rapidly
  - Develop high performance power take off and controller
  - Build a small scale model machine set
  - Design civil works, and assess fish mortality and stakeholder acceptance
  - Assess effect on grid stability and electricity markets

Objectives of ALPHEUS

- WP2: Develop a low-head reversible RPT that is efficient in both pump and turbine modes, aiming for >80% round-trip efficiency
- WP3: Develop a PTO for high efficiency at a range of heads via control of rotational speed
- WP4: Build a 50kW model machine set (combined RPT and PTO) for testing at realistic head and flowrate in the laboratory, and assess the potential for fish mortality
- WP5: Assess potential EU sites for feasibility, design the civil structures (dam, powerhouse), and assess robustness of the design
- WP6: Assess the effect of the technology on grid stability and electricity prices



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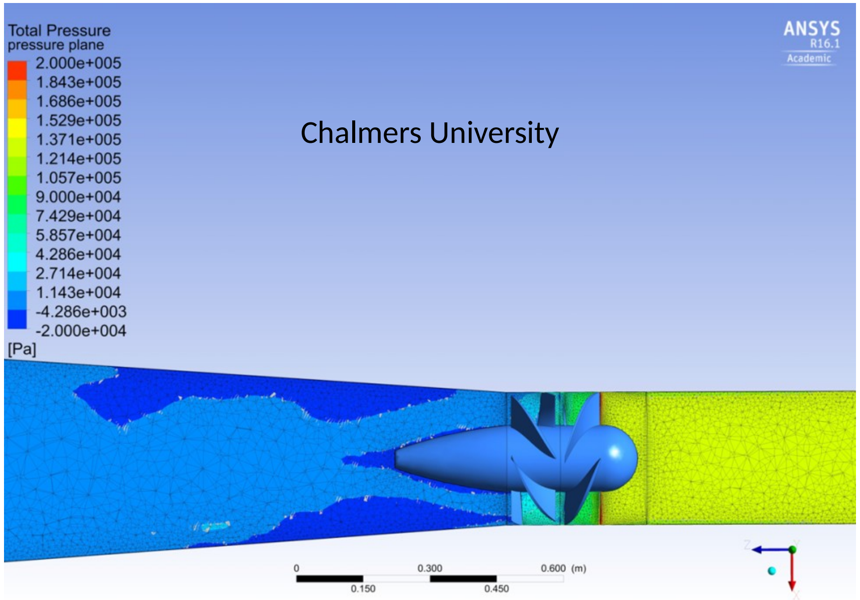
WP2: Turbine design

- Validate computational fluid dynamics (CFD) simulations on small scale laboratory turbines
- Use CFD and structural analysis to optimize RPT for efficiency and mode switching behaviour
- Design both counter-rotating propeller and positive displacement RPT’s
- Assess fish mortality

CHALMERS
UNIVERSITY OF TECHNOLOGY

Advanced Design Technology

NTNU



Chalmers University

UNIVERSITÀ DEGLI STUDI DELLA Tuscia

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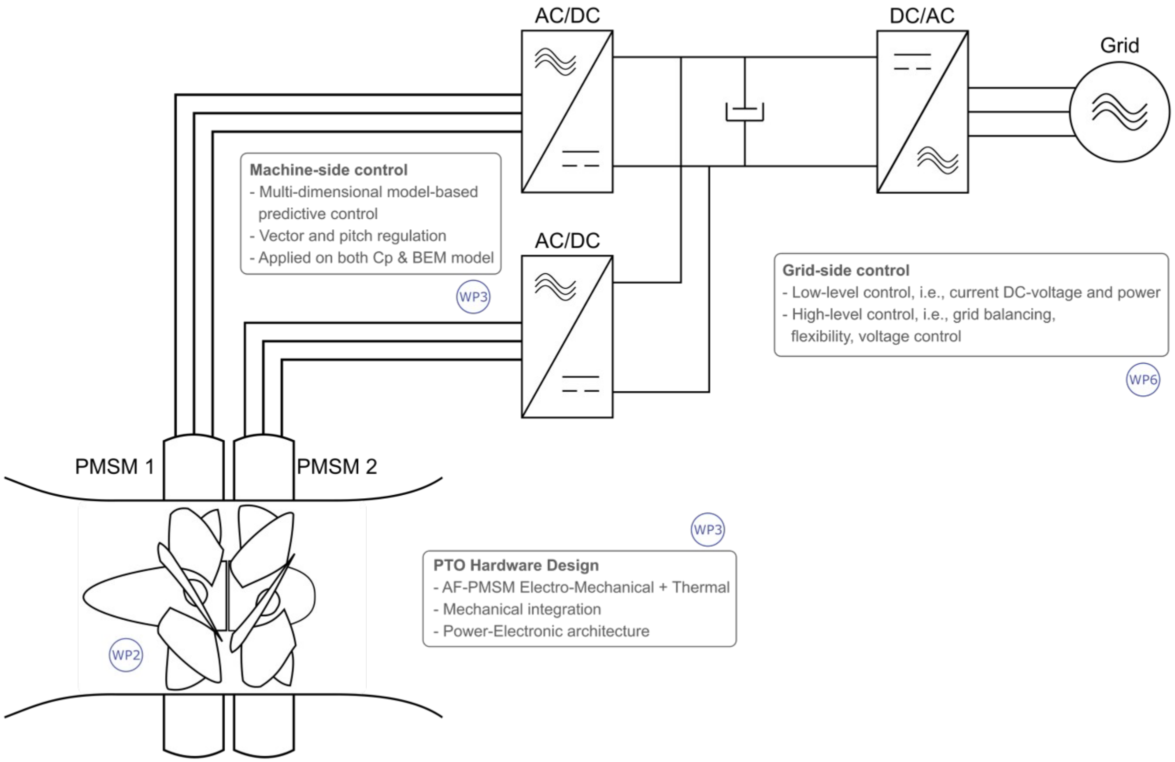
WP3: PTO design and construction

- Differential rotational speed for 2 rotors
- Control system for rotational speed and inlet gates
- Dry testing of 50kW PTO



Machine-side control
- Multi-dimensional model-based predictive control
- Vector and pitch regulation
- Applied on both Cp & BEM model

Grid-side control
- Low-level control, i.e., current DC-voltage and power
- High-level control, i.e., grid balancing, flexibility, voltage control

PTO Hardware Design
- AF-PMSM Electro-Mechanical + Thermal
- Mechanical integration
- Power-Electronic architecture

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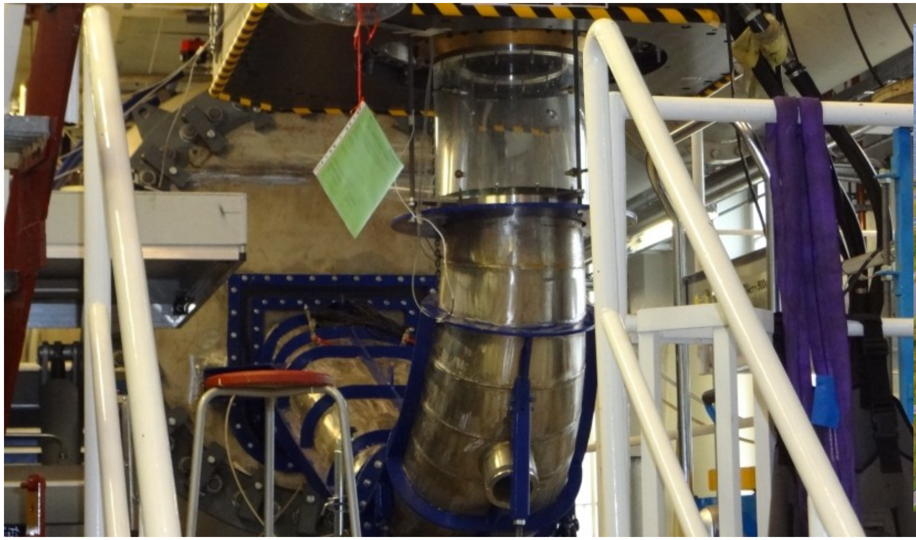
WP4: Integration of RPT and PTO

- Test 50kW model machine set in TU Braunschweig hydraulics lab at up to 10 m head and 1 m^3/s flowrate
- Measure structural stresses to validate WP2 structural model results
- Measure effectiveness of fish screens at a tidal sluice or pump station



https://www.ntnu.edu/

https://www.bt-projects.com/

TU Delft

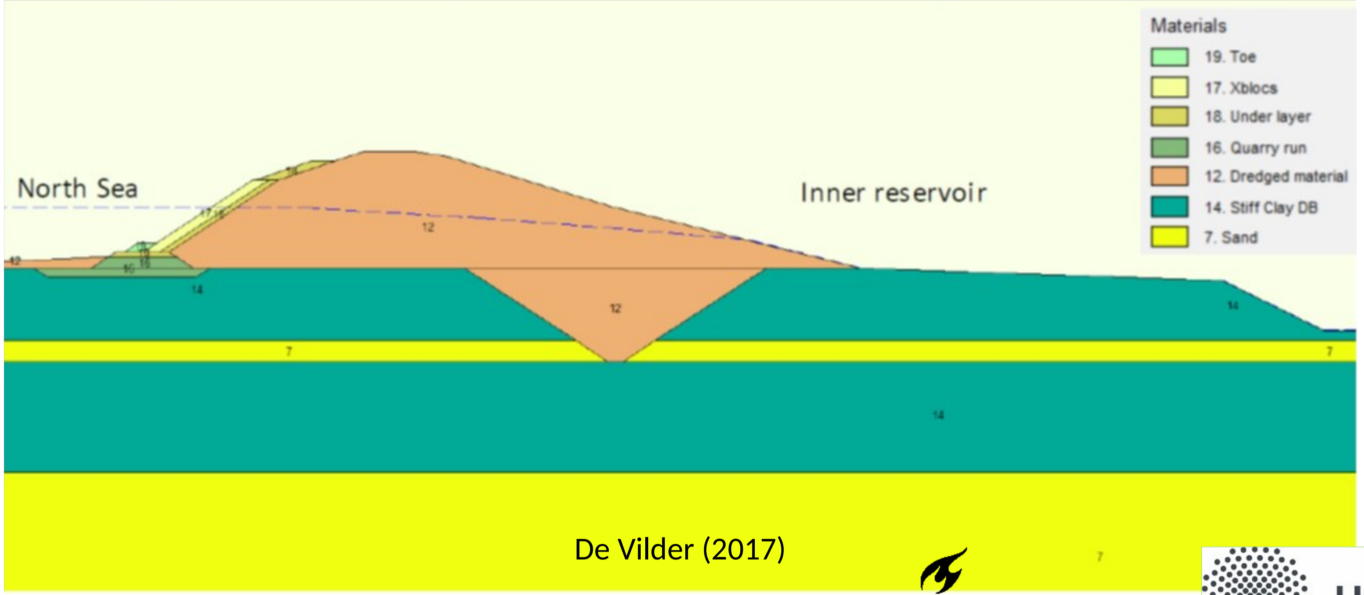
Technische Universität Braunschweig

Università degli Studi della Tuscia

Universität Stuttgart

WP5: Site assessment and civil design

- Wave modelling and geographical/environmental data collection to generate GIS layers for identification of appropriate sites around Europe
- Comparison of new and retrofit existing structures for low head pumped hydro storage
- Geotechnical, hydraulic, and structural design of facilities at selected sites
- Estimate of construction and maintenance costs
- Environmental impact assessment and stakeholder interviews



De Vilder (2017)

WP6: Effect on grid stability and flexibility

- Grid simulation with local storage
- Short term frequency regulation
- Long term supply smoothing
- Economic evaluation of flexibility and regulatory constraints, along with estimation of the Levelized Cost of Storage (LCOS) and Energy Storage on Investment (ESOI) of conceptual projects

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UNESCO IHE DELFT

TU Delft

https://en.wikipedia.org/

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