

Institute of Hydraulic Engineering and Water Resources

Value of Pumped Storage Hydropower

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Älteste PSKW Eingeweiher in Schaffhausen seit 106 Jahren im Betrieb

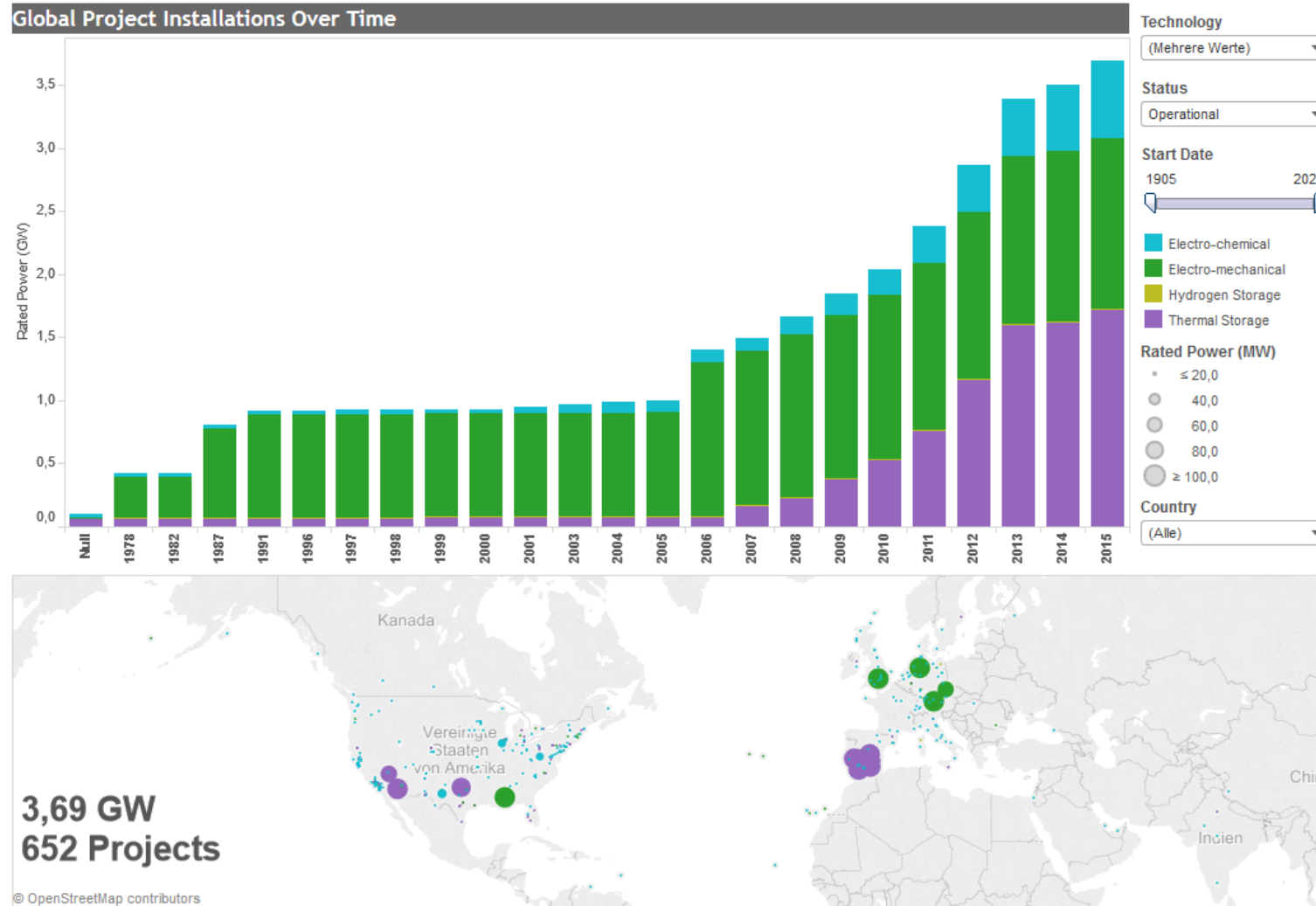
Leistung: 5 MW
Höhe 144 m
Speicher: 70 000 m³



(Quelle: Von Wandervogel - Eigenes Werk, CC BY-SA 3.0,
<https://commons.wikimedia.org/w/index.php?curid=12644156>)

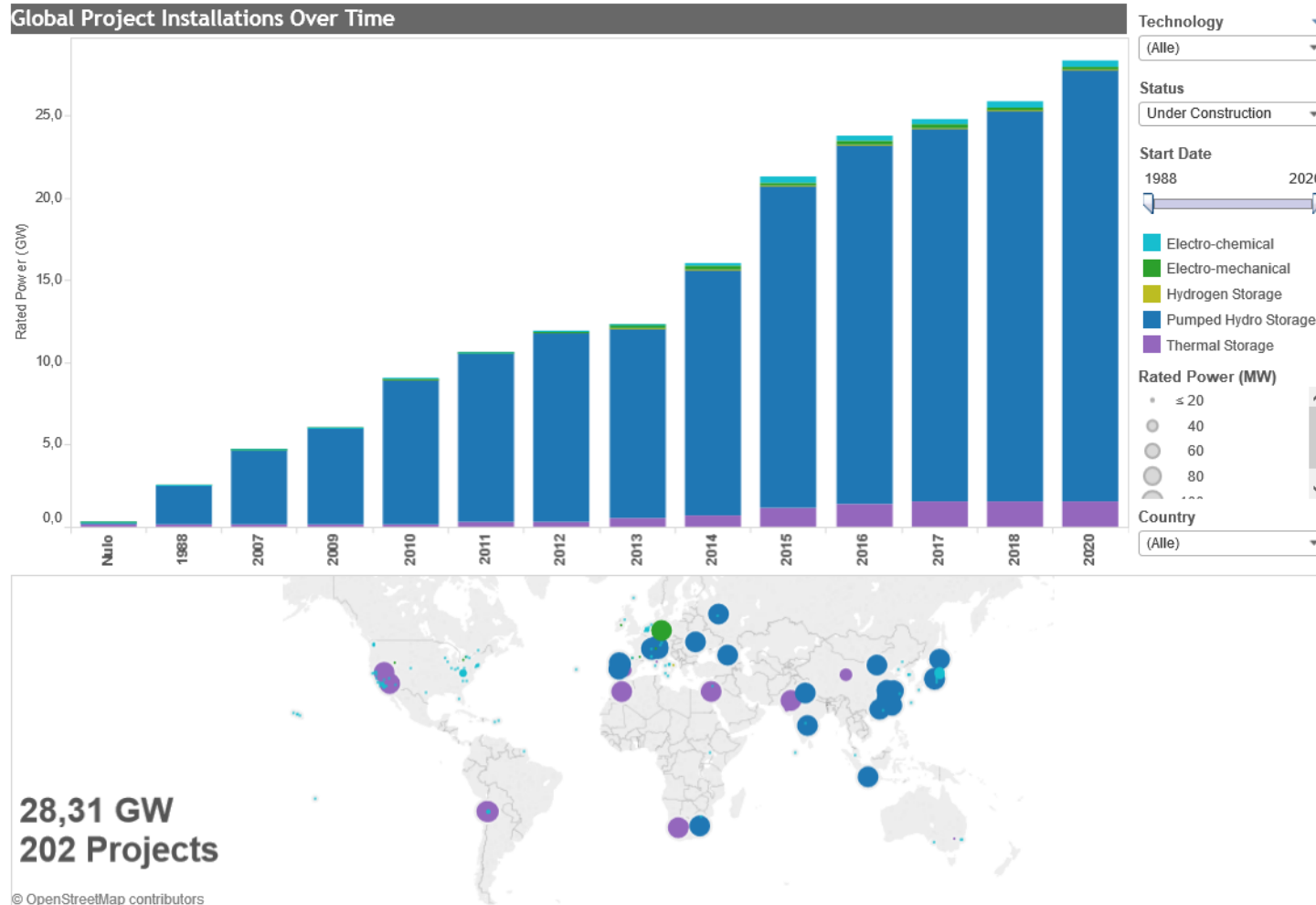
DOE Global Energy Storage Database

Last Updated 26.10.2015 16:20:26



DOE Global Energy Storage Database

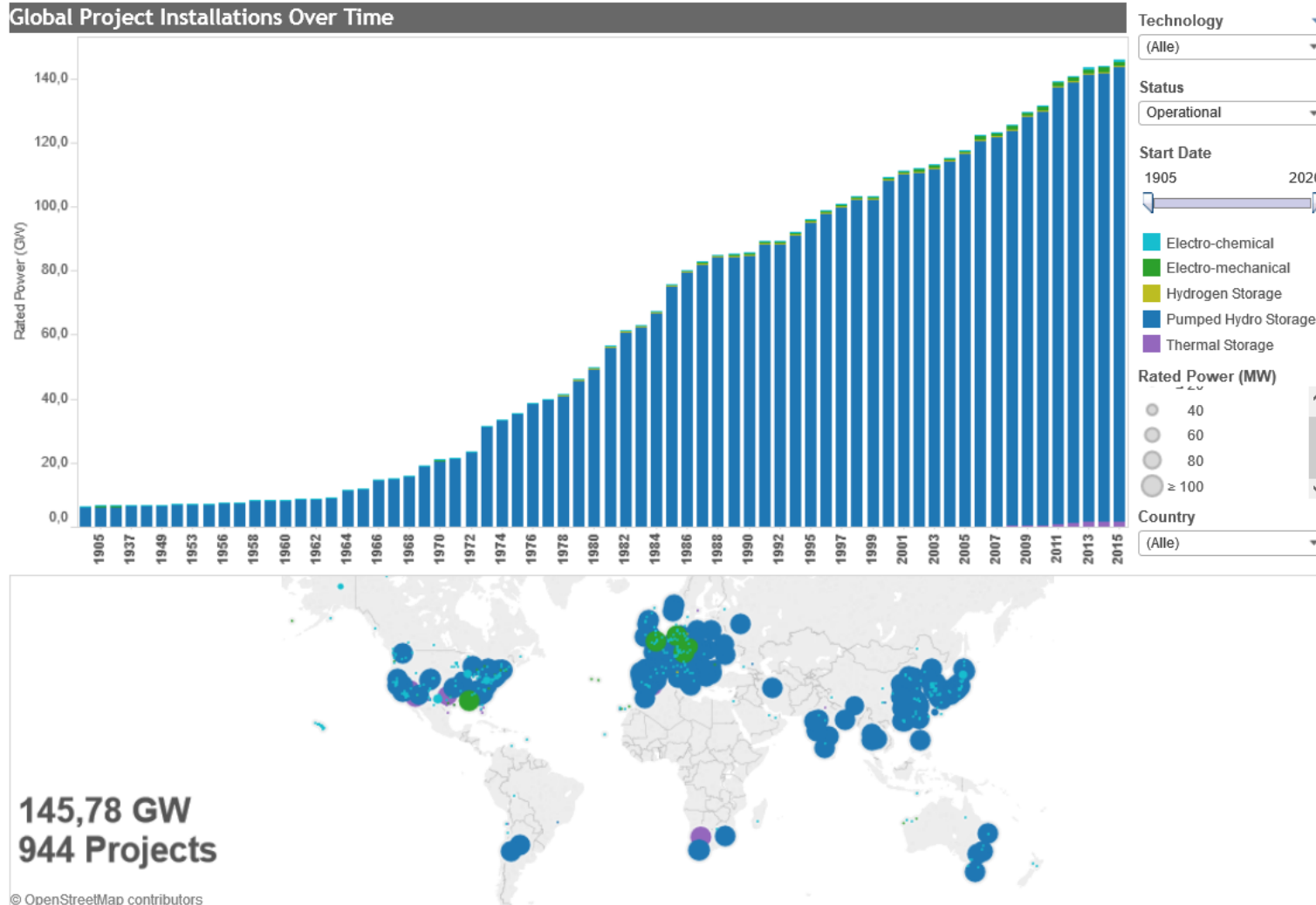
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The DOE Global Energy Storage Database (<http://www.energystorageexchange.org/>) is powered by Sandia Corporation (<http://www.sandia.gov/>) and Strategen Consulting, LLC (<http://strategen.com/>)

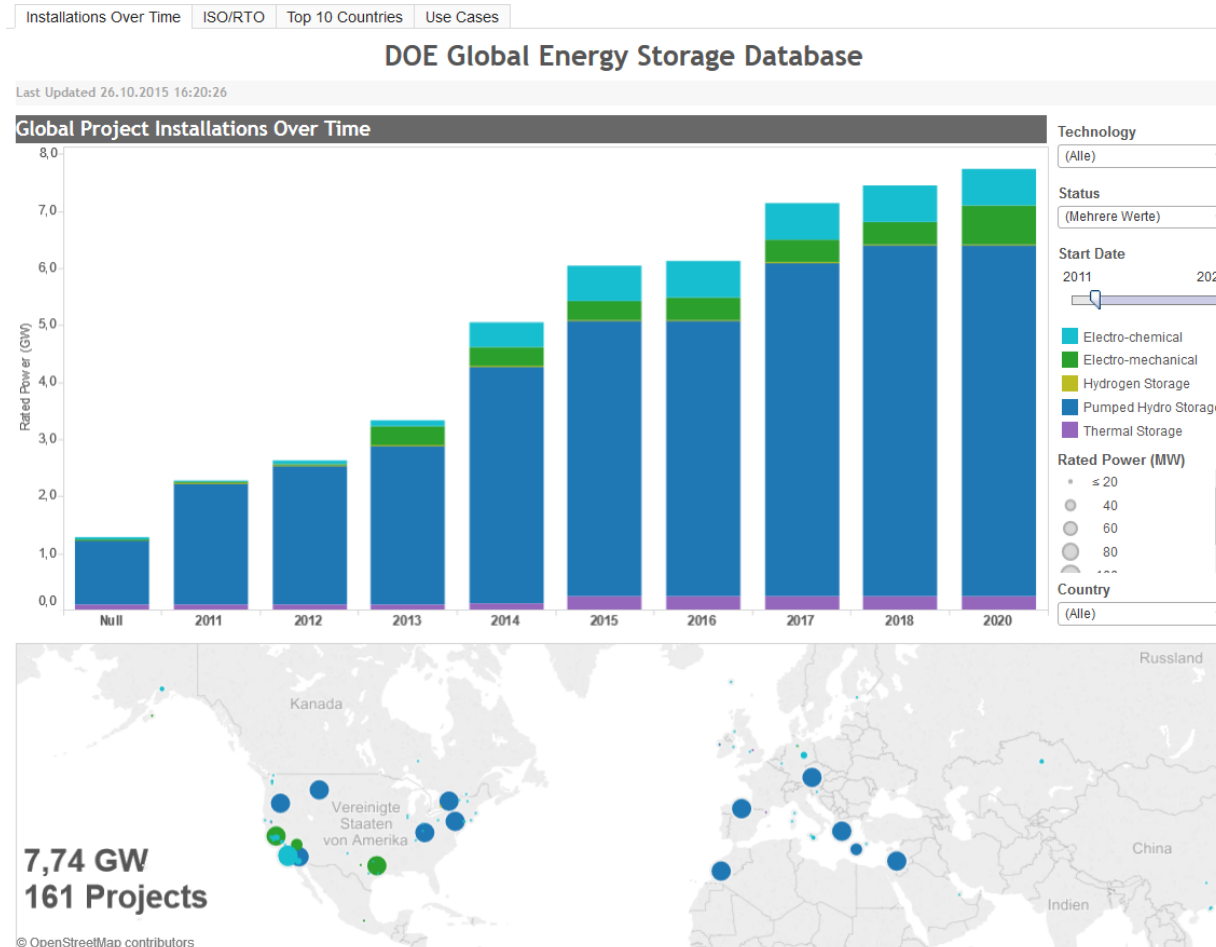
DOE Global Energy Storage Database

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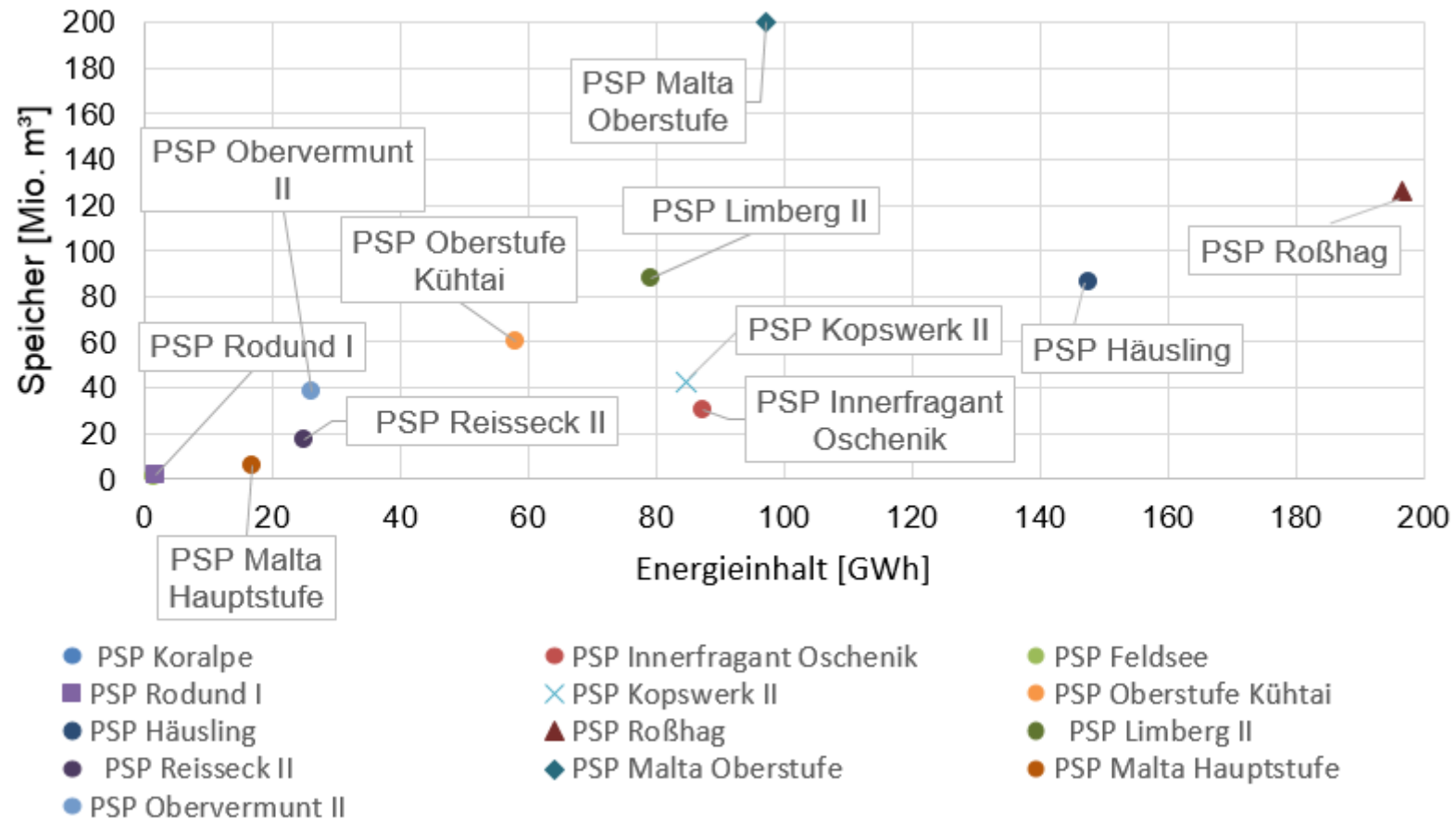
The DOE Global Energy Storage Database (<http://www.energystorageexchange.org/>) is powered by Sandia Corporation (<http://www.sandia.gov/>) and Straten Consulting, LLC (<http://straten.com/>)

Announced and contracted projects

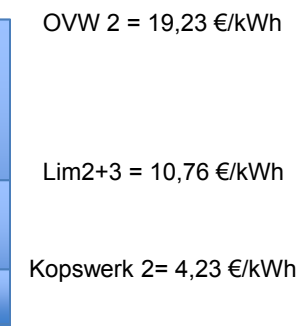
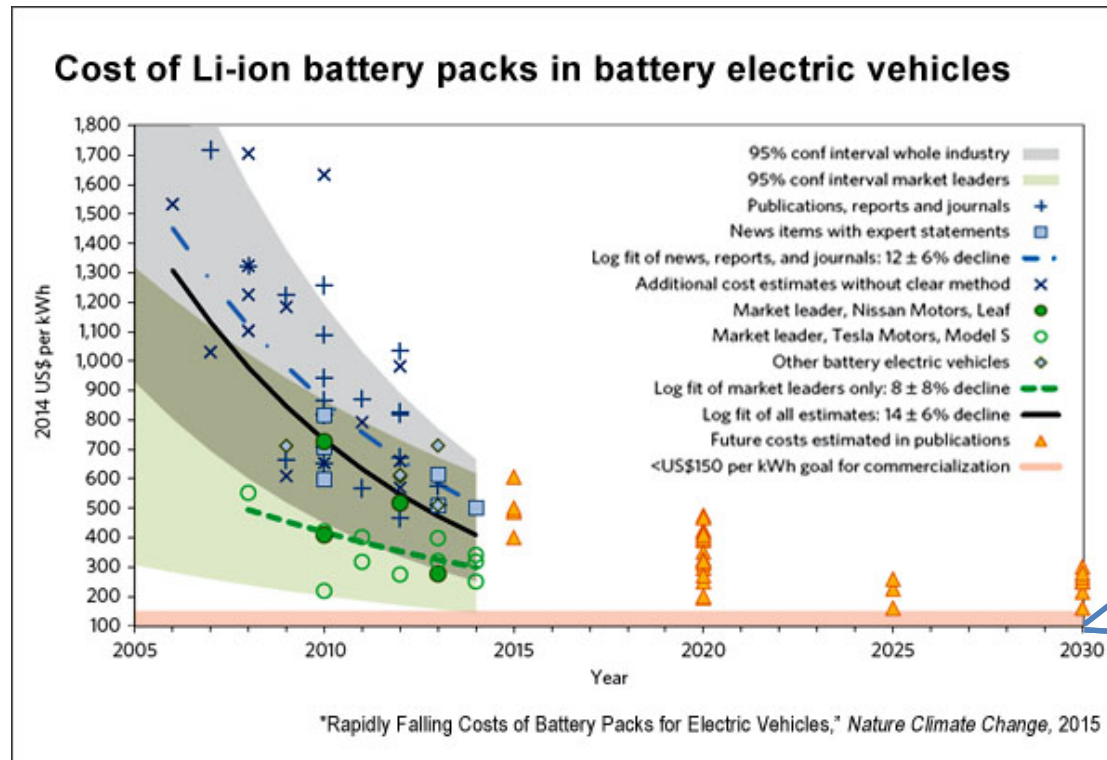


Conclusion → more small batteries than some large PSH but the main power is in PSH

Österreichische PSKW



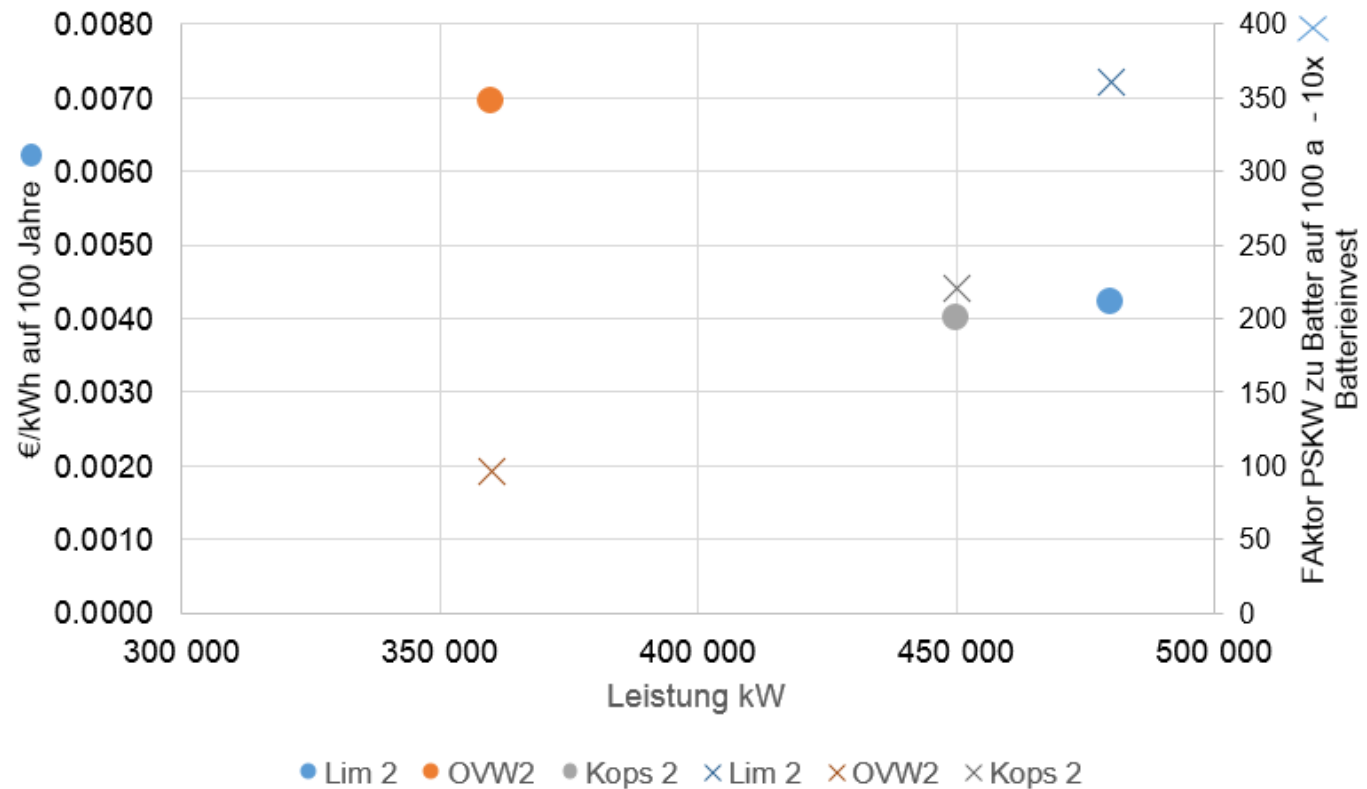
Cost of Battery packs vs. spez. Kosten PSKW



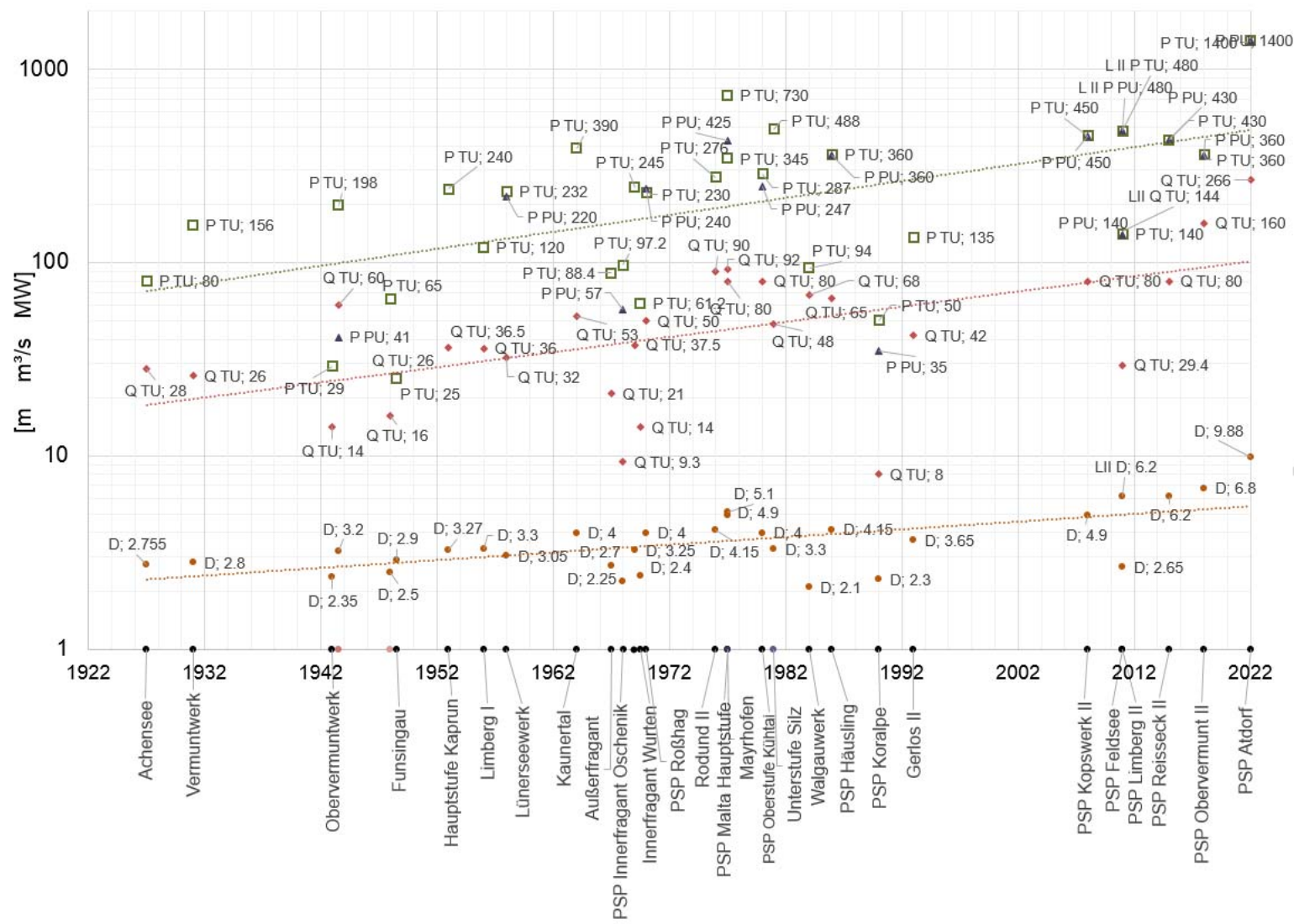
Quelle: <http://rameznaam.com/2015/04/14/energy-storage-about-to-get-big-and-cheap/>

Kostenvergleich Investitionskosten : PSKW Limberg 2 und Limberg 3 ~ 850 Mio. € / 79 GWh → 10,76 €/kWh
 Kopswerk II 360 Mio. € / 85 GWh → 4,23 €/kWh
 Obervermuntwerk II 500 Mio. € / 26 GWh → 19,23 €/kWh

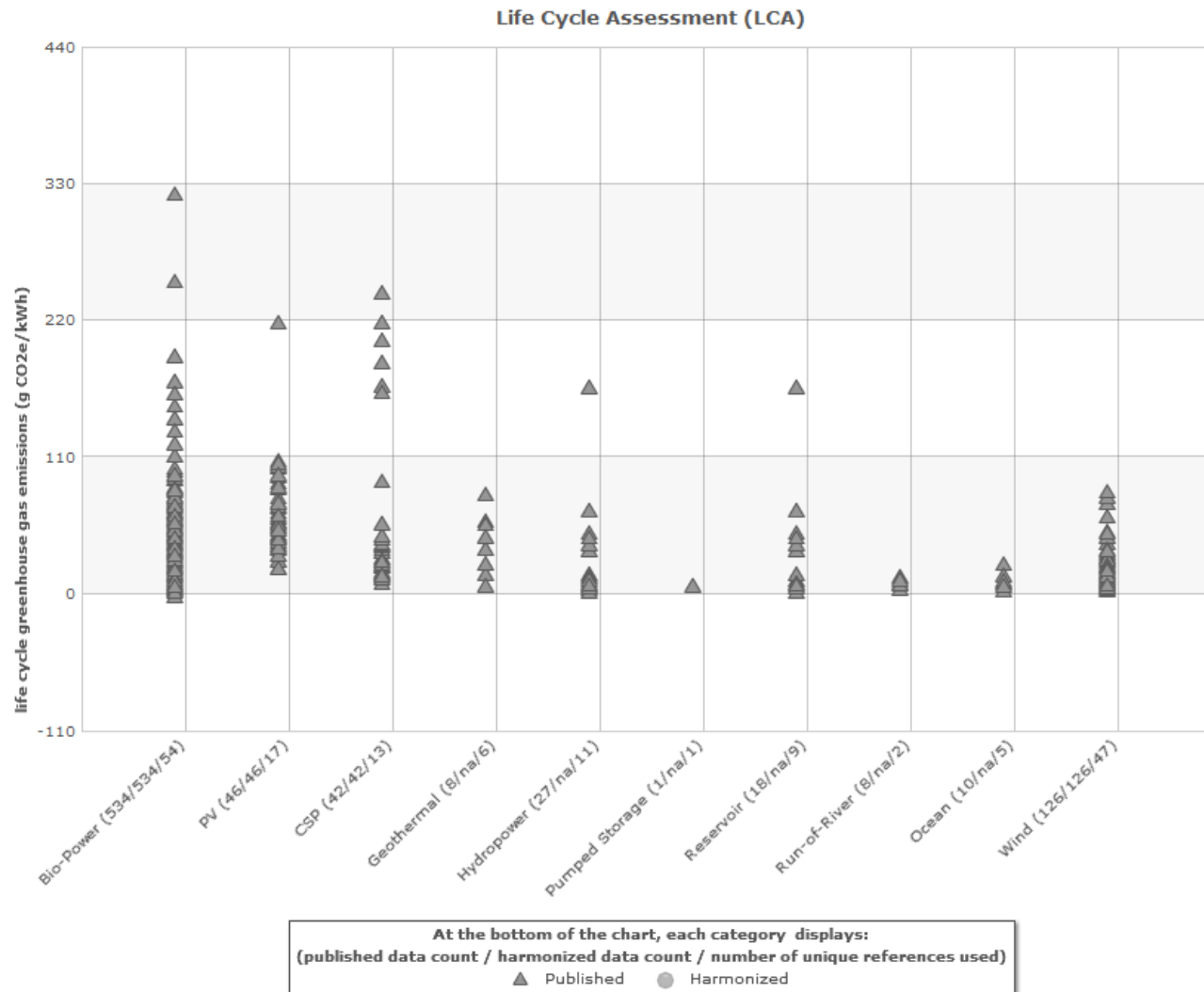
Spezifische kosten elektr. Speicherung



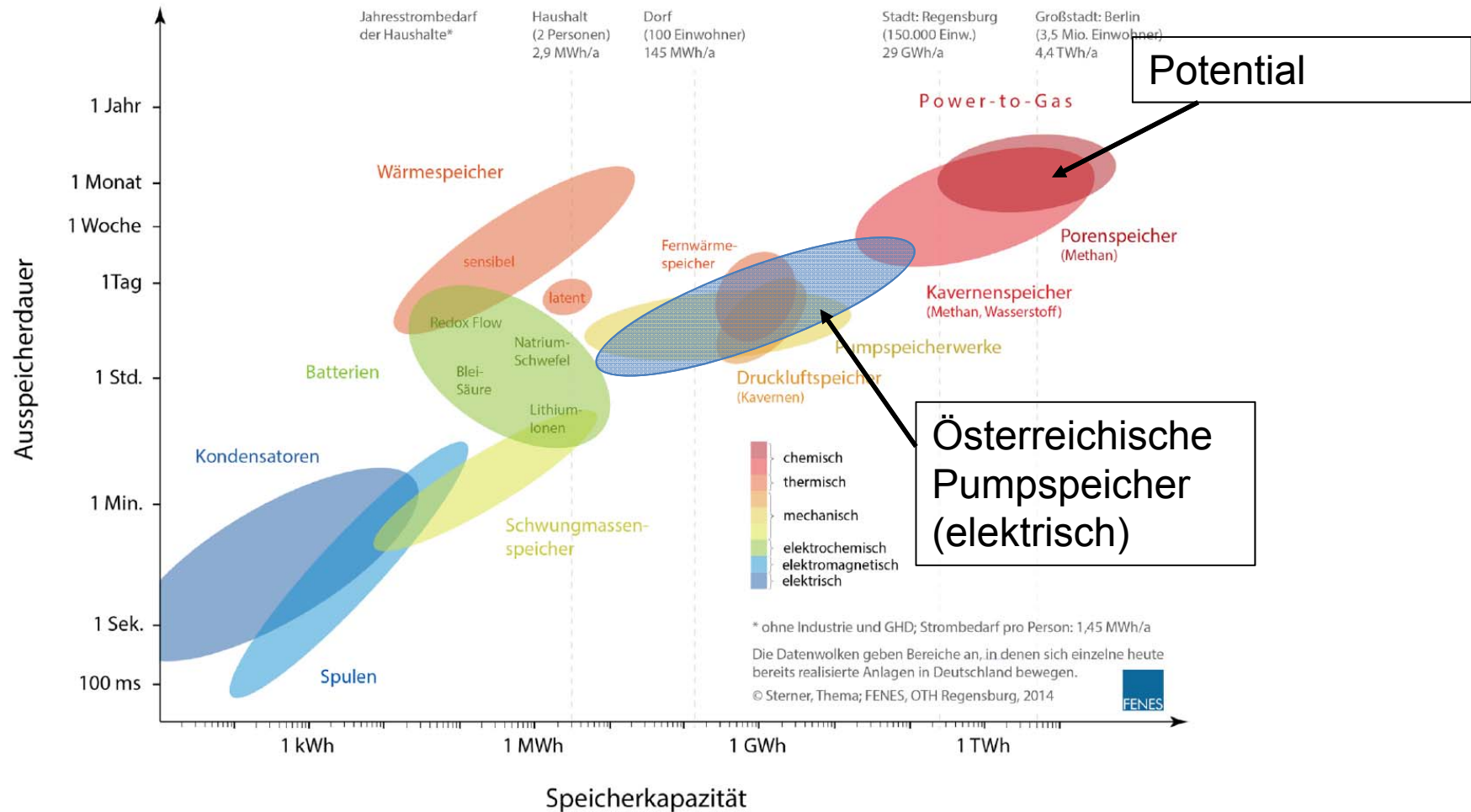
Trend Hochdruckanlagen – PSKW in Österreich



Life cycle assessment – Power production

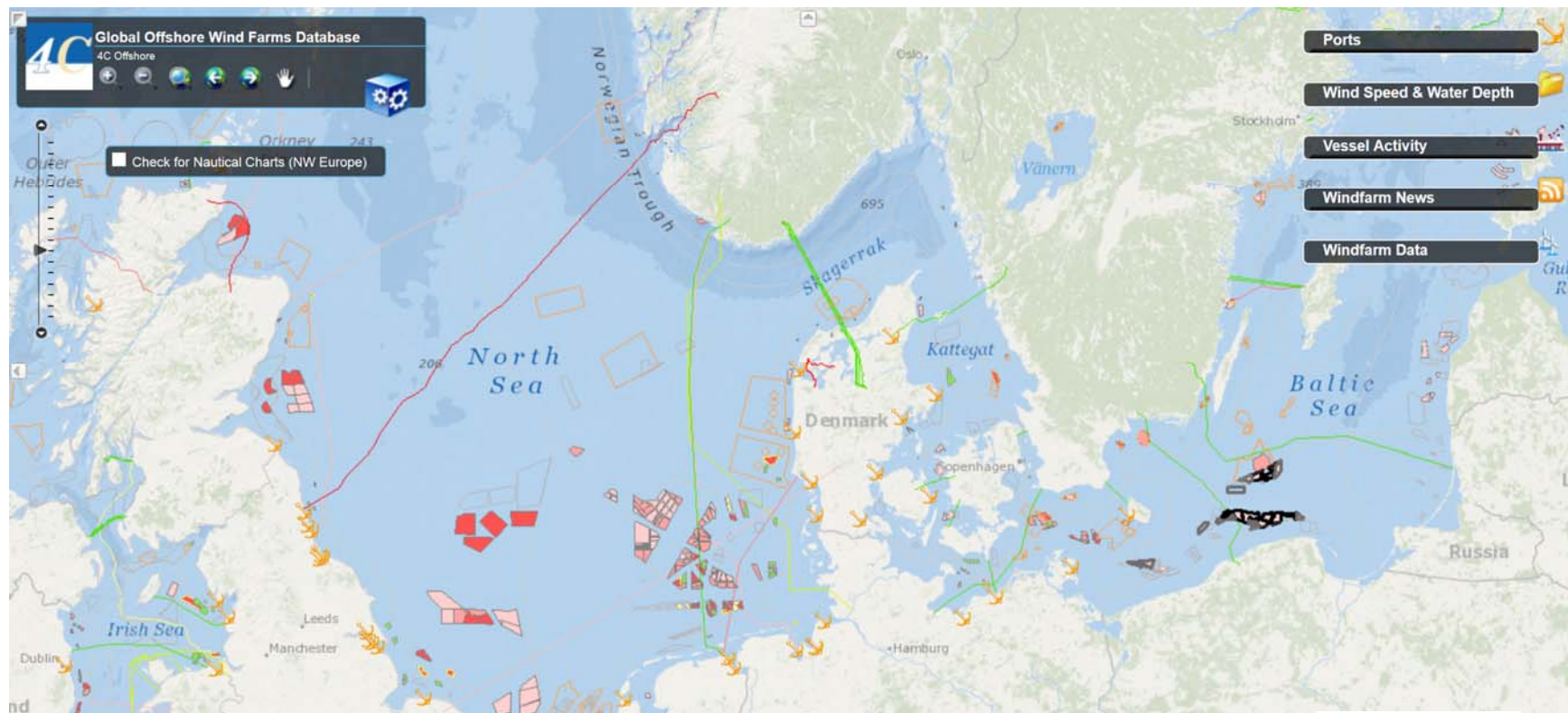


Energiespeicher



Quelle: Sterner, Stadler, 2014 - bearbeitet

Nordsee Situation – PSKW - Kabel



Quelle: foroffshore.com



Vergleich Blåsjø 50 GW PSKW

Blåsjø Super PSH

Energy content	7 800 000 000	kWh	
Installed capacity	50 000 000	kW	
Emptying time	172	h	
Discharge	5000	m ³ /s	
Construction cost PSH only	25 000 000 000	€	500 Mio.€/1000 MW
	3.21	€/kWh	
Connector costs	70 000 000 000	€	1.4 Mrd. für 1000 MW
Lower storage costs	5 000 000 000	€	
Total cost sum:	100 000 000 000	€	
	12.8	€/kWh	
Lifetime min.	100	years	
2000h/a - 100 years	10 000 000 000 000	kWh/life	
	0.010	€/kWh life	
future price Battery	150	€/kWh	
Guarnteed lifetime	10	years	

Cost Faktor comparison battery vs. PSH

only PSH	468	[-]
with cable	117	[-]

future price Powerwall	150	€/kWh
Guarnteed lifetime	100	years

Cost Faktor comparison Battery vs. PSH

only PSH	47	[-]
with cable	12	[-]



Vergleich Blåsjø 10 GW PSKW

Blåsjø Super PSH

Energy content	7 800 000 000	kWh	
Installed capacity	10 000 000	kW	
Emptying time	862	h	
Discharge	1000	m ³ /s	
Construction cost PSH only	5 000 000 000	€	500 Mio.€/1000 MW

	0.64	€/kWh	
Connector costs	14 000 000 000	€	1.4 Mrd. für 1000 MW
Lower storage costs	1 000 000 000	€	
Total cost sum:	20 000 000 000	€	

	2.6	€/kWh	
Lifetime min.	100	years	
2000h/a - 100 years	2 000 000 000 000	kWh/life	
	0.010	€/kWh life	
future price Battery	150	€/kWh	
Guarnteed lifetime	10	years	

Cost Faktor comparison battery vs. PSH

only PSH	2340	[-]
with cable	585	[-]

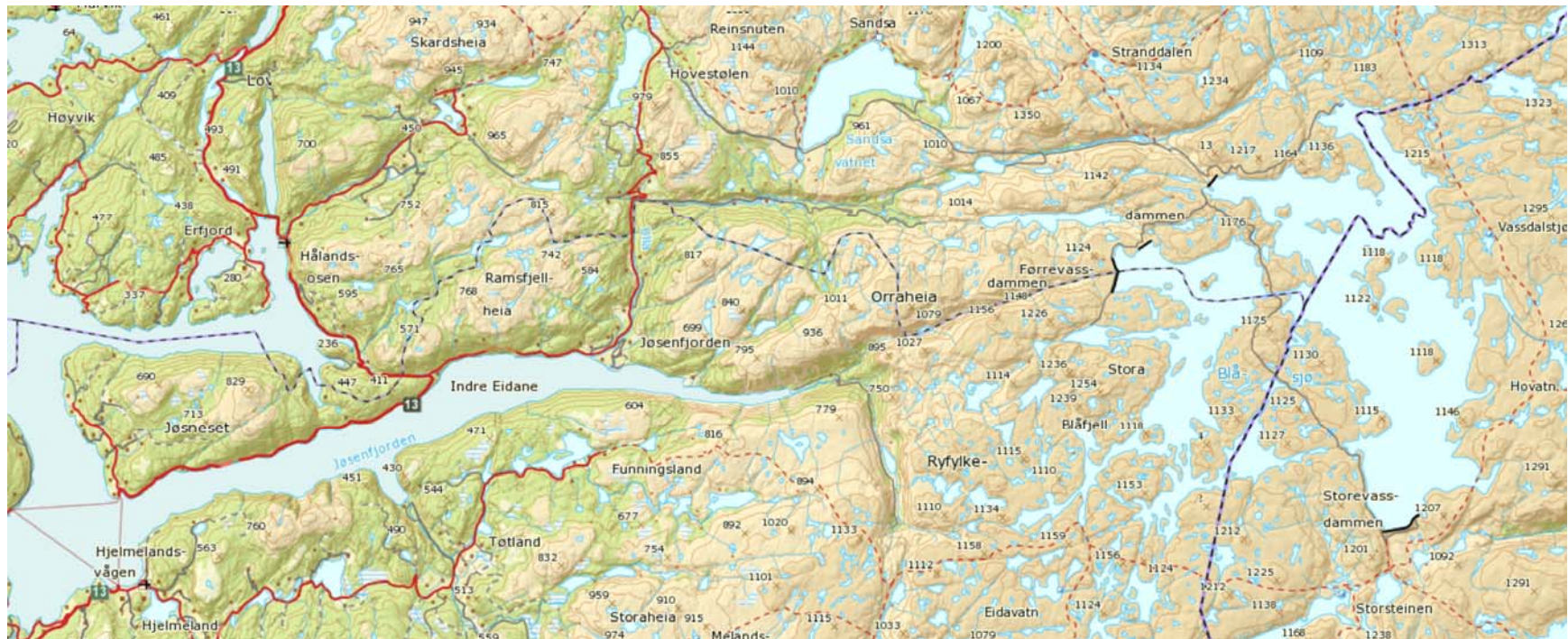
future price Powerwall	150	€/kWh
Guarnteed lifetime	100	years

Cost Faktor comparison Battery vs. PSH

only PSH	234	[-]
with cable	59	[-]



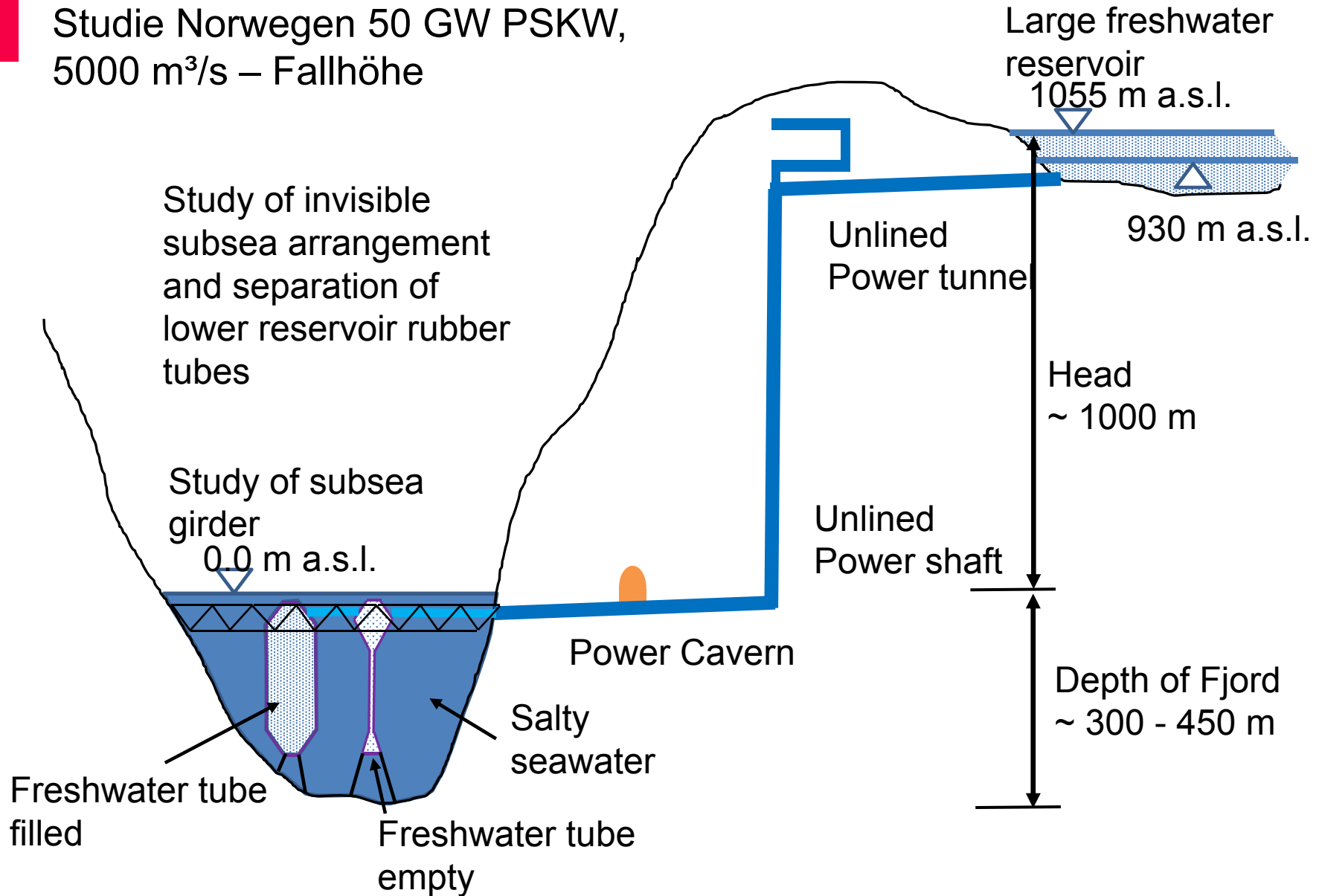
Study of Blåsjø - PSH



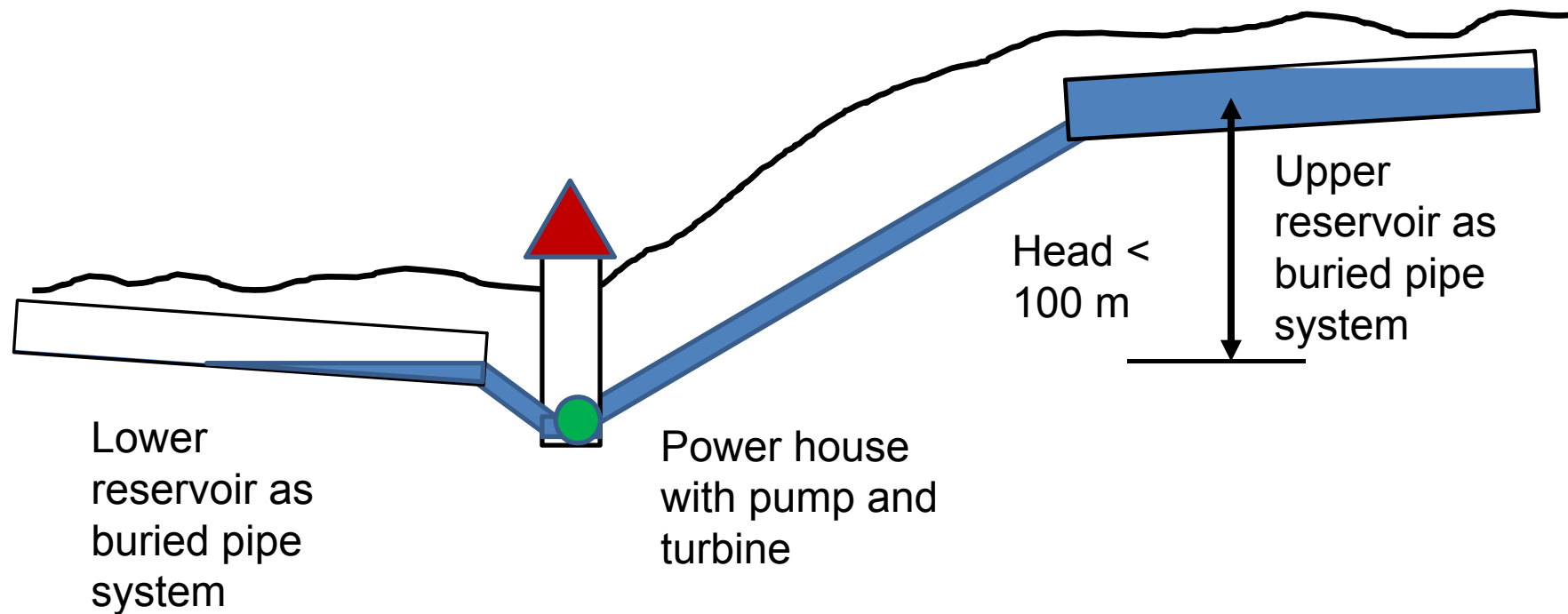
Quelle: Mareano.no



Studie Norwegen 50 GW PSKW, 5000 m³/s – Fallhöhe



Kleine PSKW im dezentralen Netz

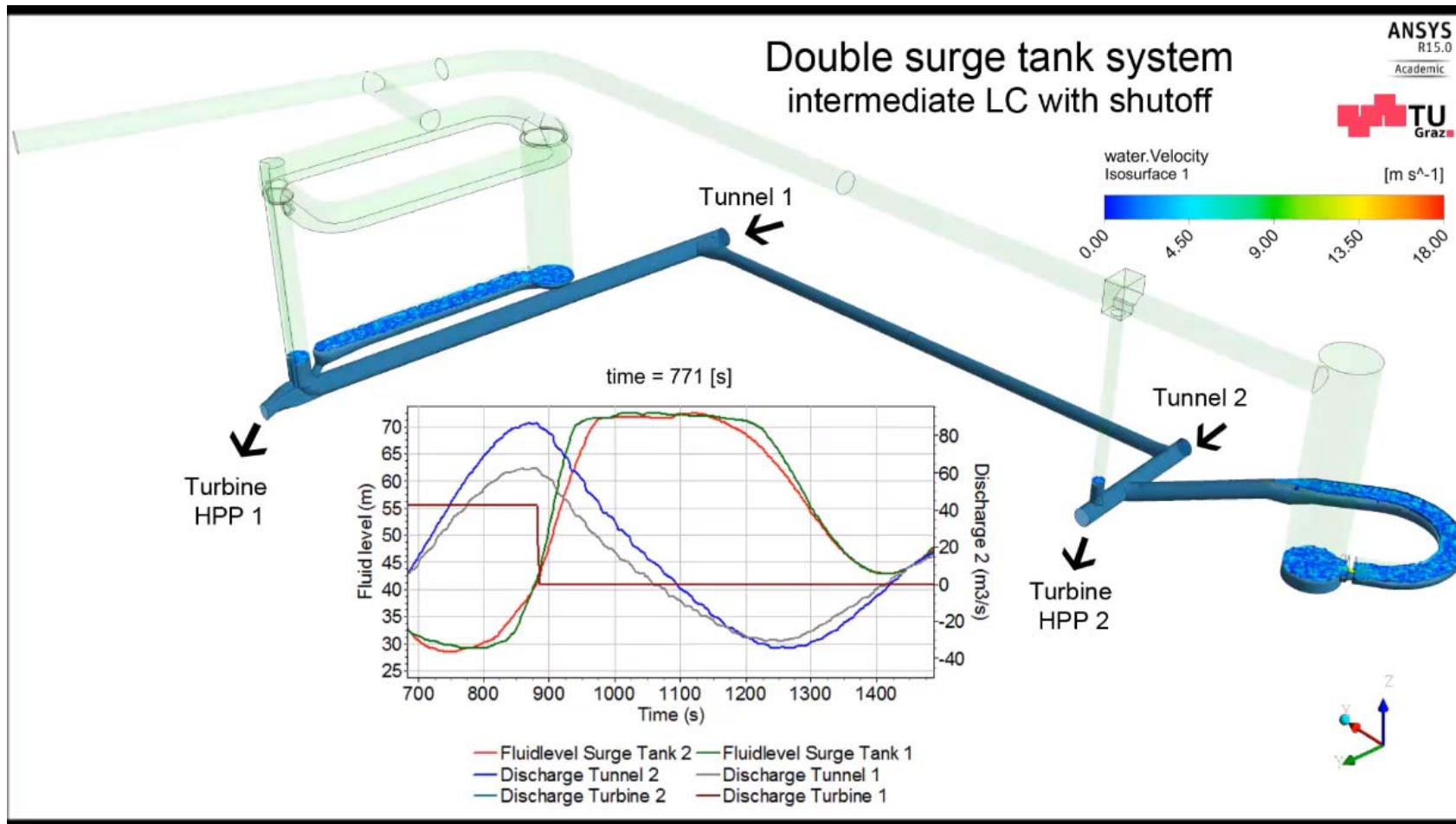


Lernkurve PSKW - Innovationen

Flexibilisierung – hohe Zyklenstabilität

- **Maschinelle**
 - Frequenzumrichter
 - Pumpturbinen
 - Volldynamische Auslegung
- **Bautechnische**
 - Komplexe Wasserschlosser (Bindeglied E-Technik, Bautechnik und Maschinenbau)
 - Regelbarkeit, Drucksstoß,
 - Druckluftwasserschlosser (PSKW Kops 2)

Bestand KW mit Ausbau einer neuen Stufe



Surge developement at TU Graz

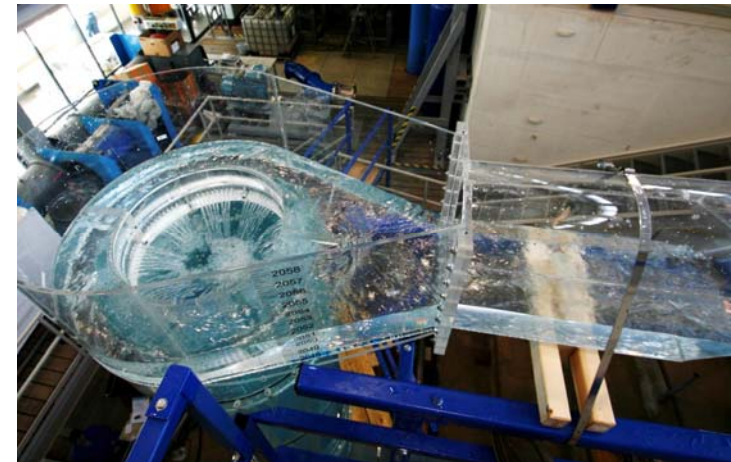
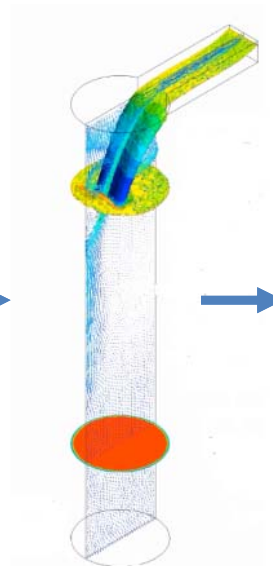
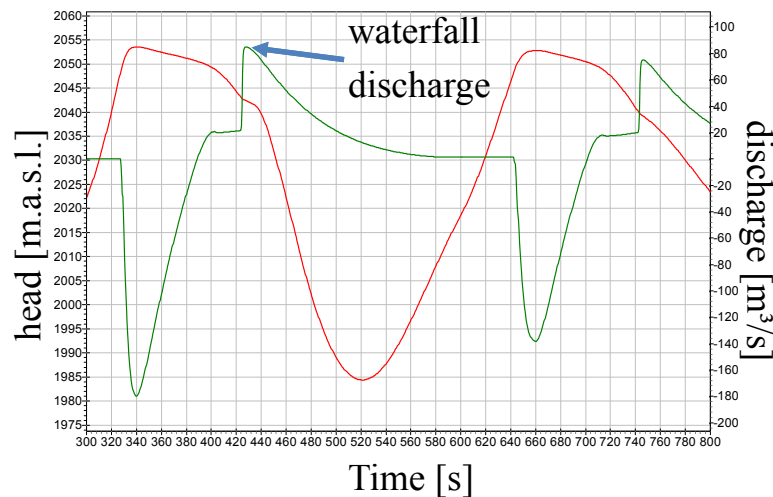
1D-Numerics



3D-Numerics



Physical model test



- Fast transient simulation
- Surge tank size
- Throttle concept
- Water hammer reflection
- Check of stability criterion

- 3D-Flow evaluation
- Variants investigation
- Multiphase flow simulations
- Throttle investigations

- Overall check
- Transient behavior of total
- Throttle proof
- Additional measurements
- Visualization

Ausblick Lernkurve PSKW

- Dezentrale PSKW
 - Kleine PSKW – evtl. Mit Wärmespeicher
- Zentraler Einsatz
 - Kombinierte PSKW mit großen Wärmespeicher als Langzeitspeicher
Isoliert, teilisoliert, Kavernensysteme
(geschlossener Wasserkreislauf)

Vorteile PSKW

- CO₂ schonende Speicherung (0,005 kg CO₂ eq/kWh)
- Günstigste Stromspeicherung < 10ct/KWh (auf 20 Jahre)

References

- Solvang et. al. “Norwegian Hydropower for large-scale energy balancing needs“ Sintef Energy Research, TR A7227, 2014
- Killingtveit Presentation: “ Design of Future Pumped Storage Hydropower in Norway “ CEDREN, (Sintef, NTNU, NINA)
- Vahrenholt “ Die Wettbewerbsfähigkeit erneuerbarer Energien “ ET 2012
- Ingebretsen and Johansen, “ The Profitability of Pumped Hydro Storage in Norway “ Masterthesis, Norwegian School of Economics, Bergen 2014

Vielen Dank

