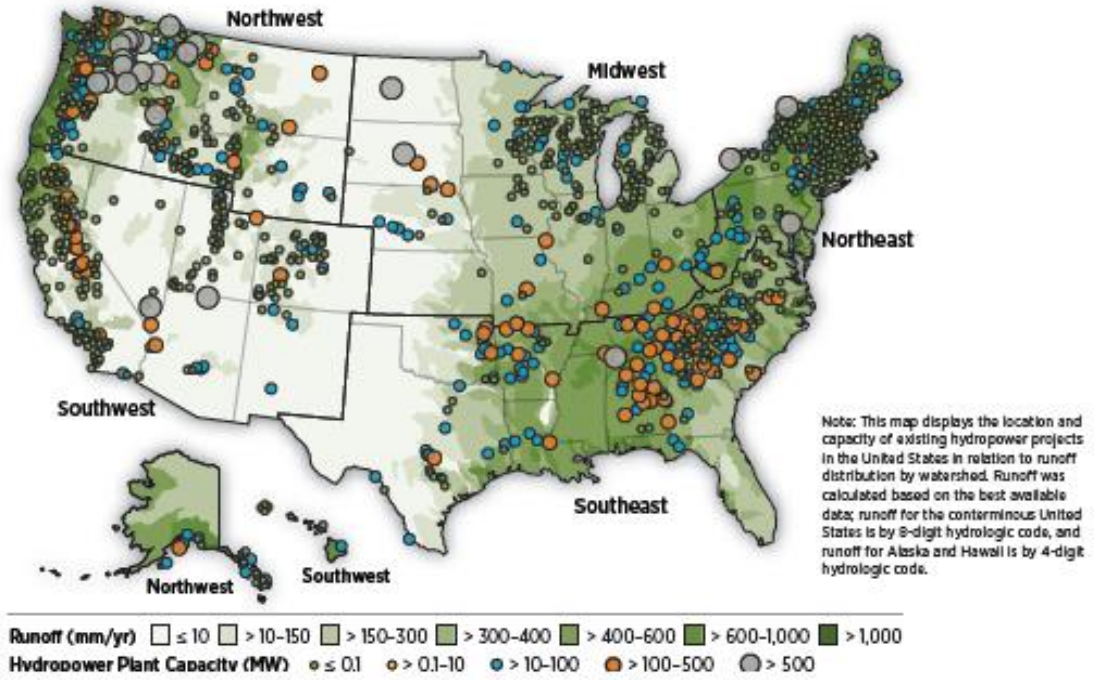
Conventional Hydro and Pumped Hydro : Contributing to & facilitating the RE transition

ESIG Fall Workshop: - Generation and Storage Technology – Status and Prospects

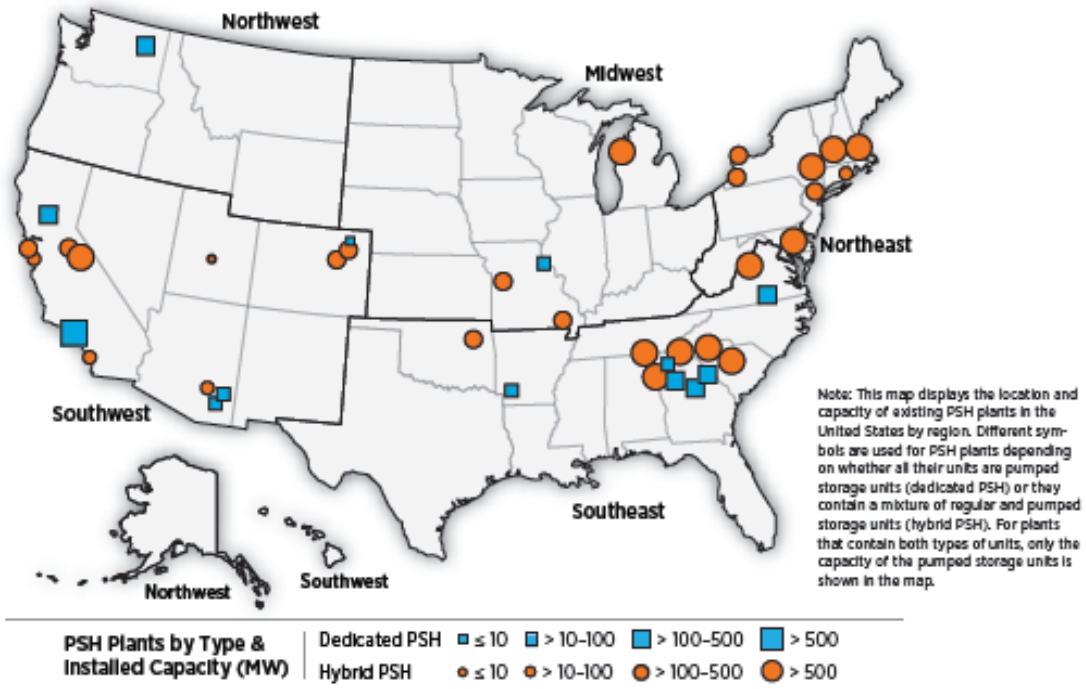
November 12, 2020

Hydro in the USA

~80 GW of Conventional Hydro



~24 GW of Pumped Storage Hydro

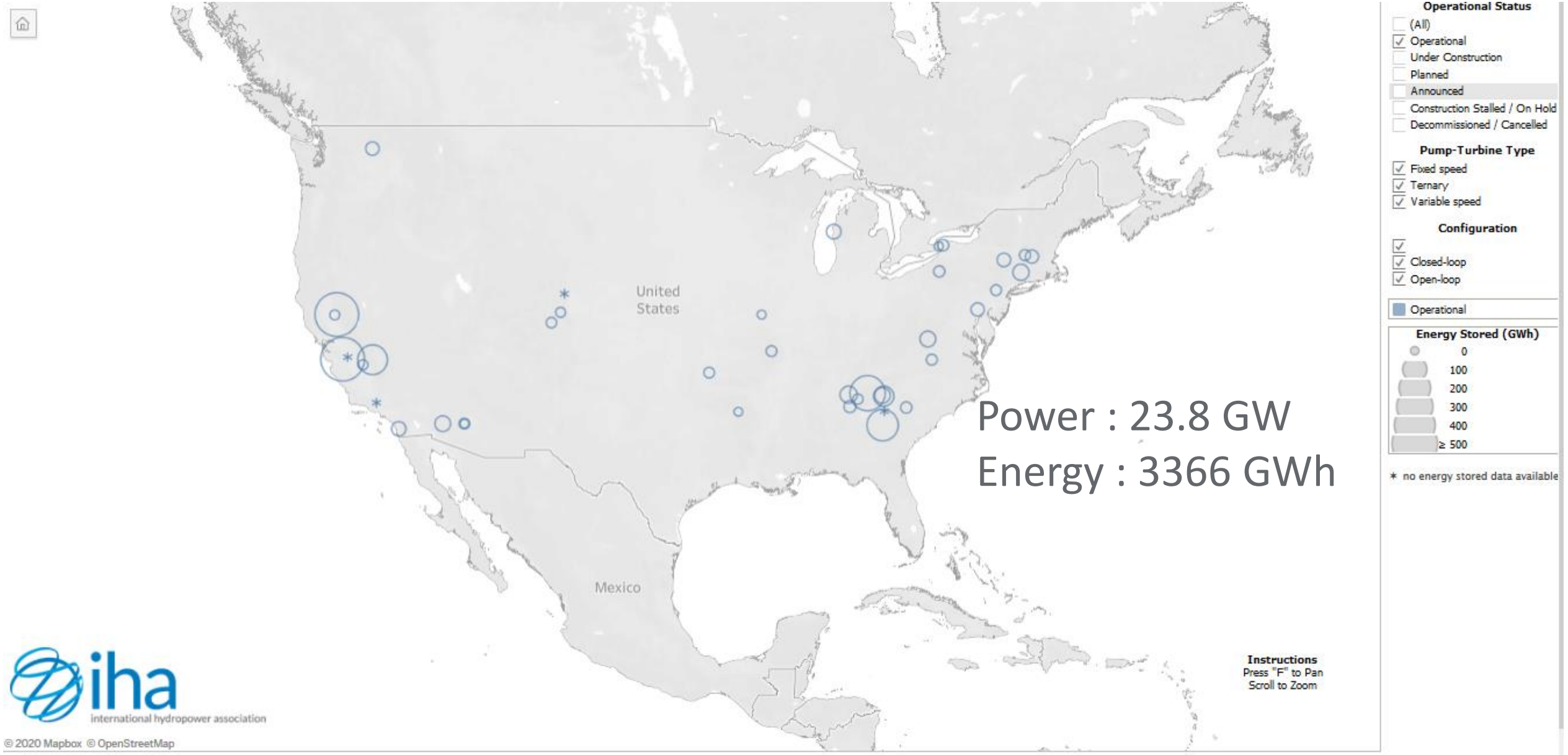


~70% adjustable / dispatchable

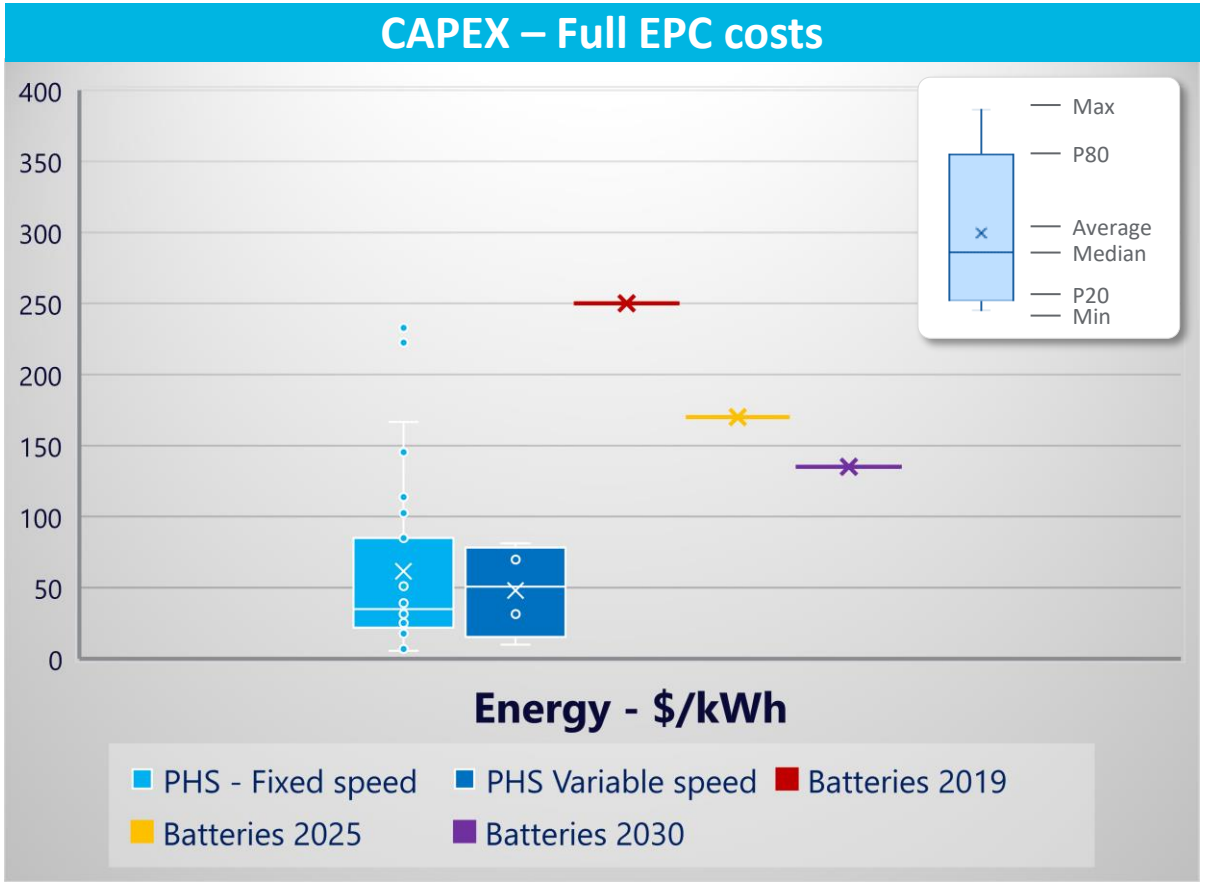
Source : Hydropower Vision, DOE July 2016

Longevity : 80% of US MWs built since 1950s

Energy Storage



Capital costs per kWh
Pumped Hydro & Li-ion Batteries



Source : GE RE Marketing, BNEF

- PHS CAPEX vary widely due to **site-specific costs**; ~20-30% of total CAPEX linked to Electro-mechanical equipment.
- Median price for PHS fixed speed ~25% lower than PHS Variable speed
- Broad range of batteries costs linked to **capacity sizing** (from 30 min up to 4+ hours)
- **Strong decrease in batteries costs to continue**: most of cost reduction driven by scale and adoption of electric vehicles, supplemented by tech advances
- Prices for energy storage systems vary a lot depending on the **power-to-energy ratio**: large-scale storage capacity of PHS has positive impact on $/kWh whereas more limited storage capacity of batteries negatively impact $/kWh

Annualized $/kWh-year

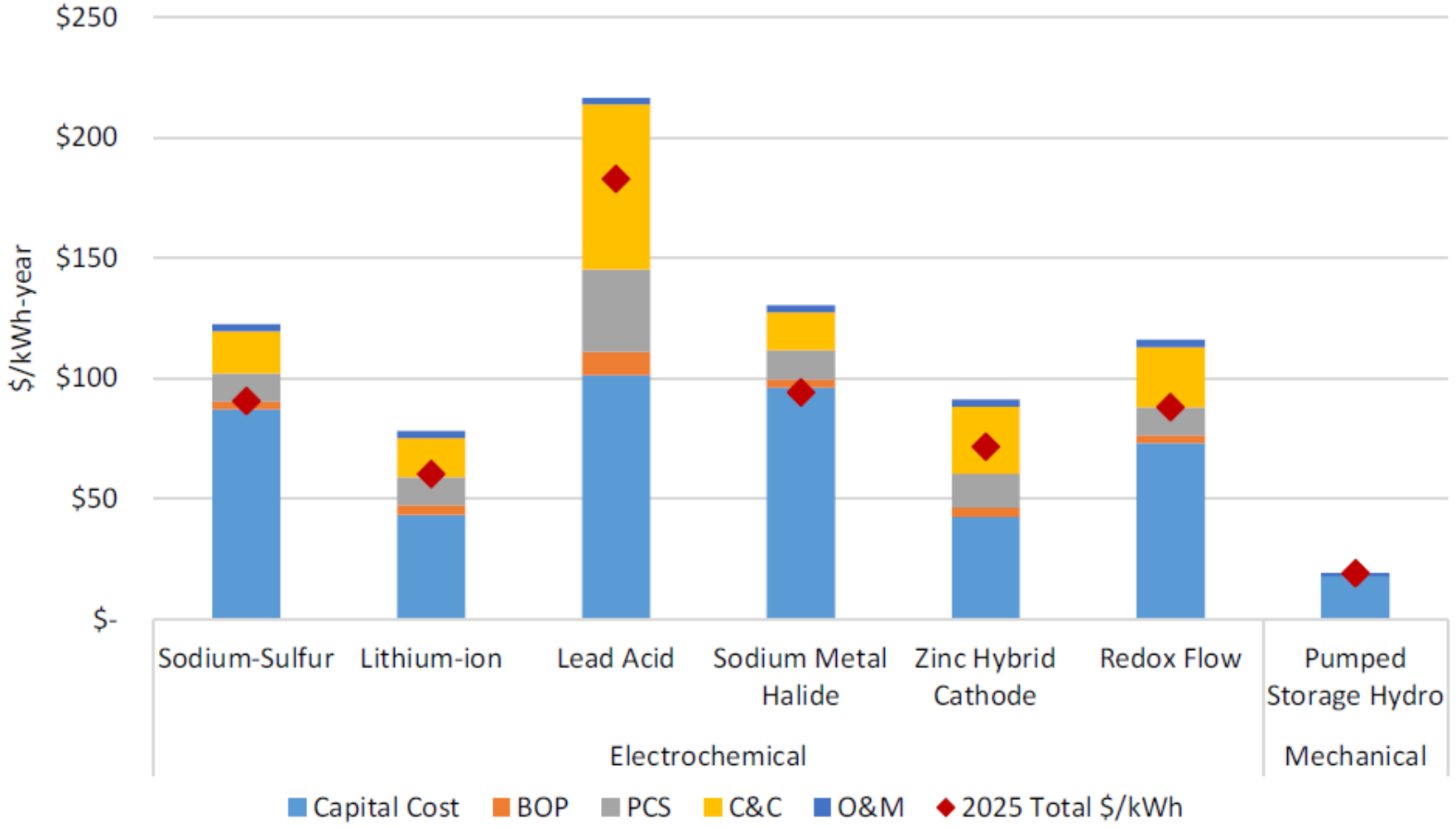


Figure 5.3. Annualized $/kWh-yr cost of battery storage technologies vs. pumped storage hydro by cost component.

Source : Energy Storage Technology and Cost Characterization Report, PNNL 28866, July 2019

21st Century ushers in Advanced Pumped Storage Technology

3 GENERATIONS OF TECHNOLOGY

1960s

1st Gen

Introduction of reversible pump-turbines

1980s - 2000s

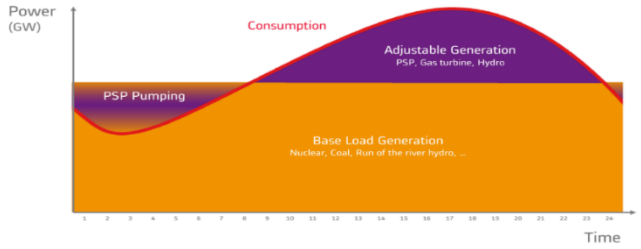
2nd Gen

Highest Efficiency (for arbitrage)

~2015

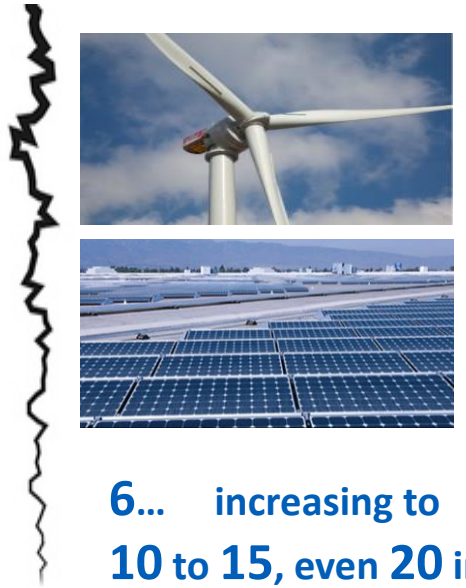
3rd Gen

Flexibility & Reliability

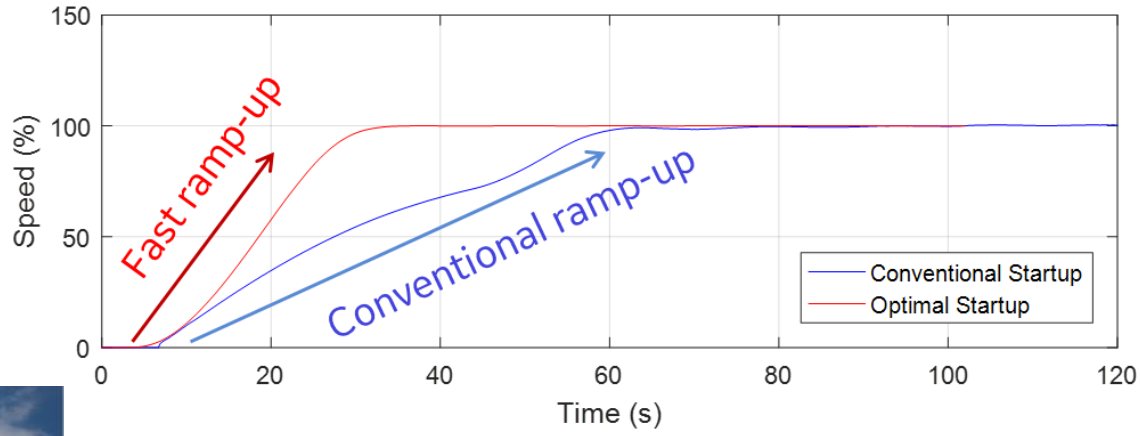


Typical # daily starts and stops

2 to 3



6… increasing to 10 to 15, even 20 in a recent request

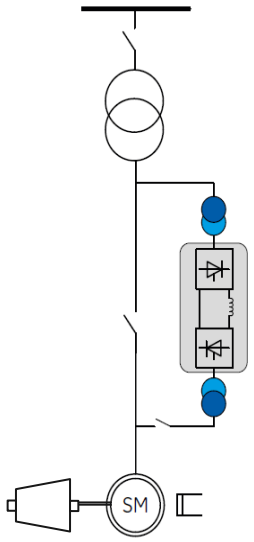


- Ramp rates once synchronized 6% per **second**
- **Fast transition** between operating modes
- **Increased flexibility** in generation (turbine) mode
- Variable speed for more **flexibility** in power generation and absorption

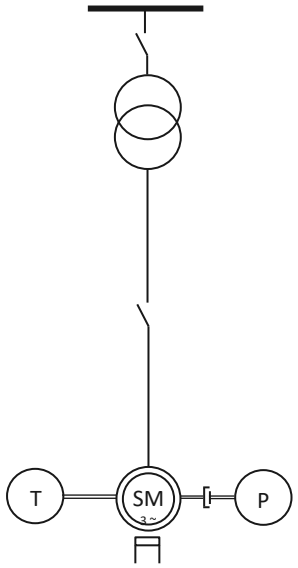
Pumped Hydro Storage (PHS) technologies

PHS System Technologies

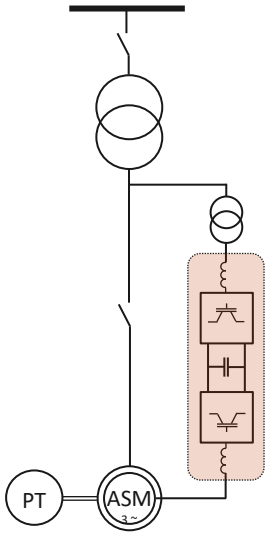
Reversible Fixed Speed



Fixed Speed Ternary

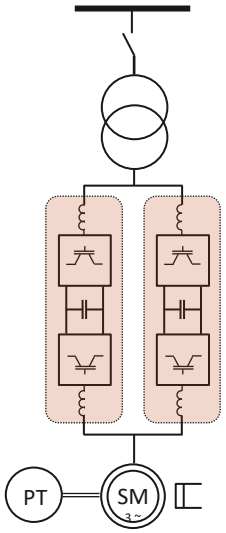


Variable Speed Doubly Fed



> 100 MVA

Variable Speed Fully Fed



<= ~100-150 MVA

Advanced PHS technology

New generation of machine for **flexibility**

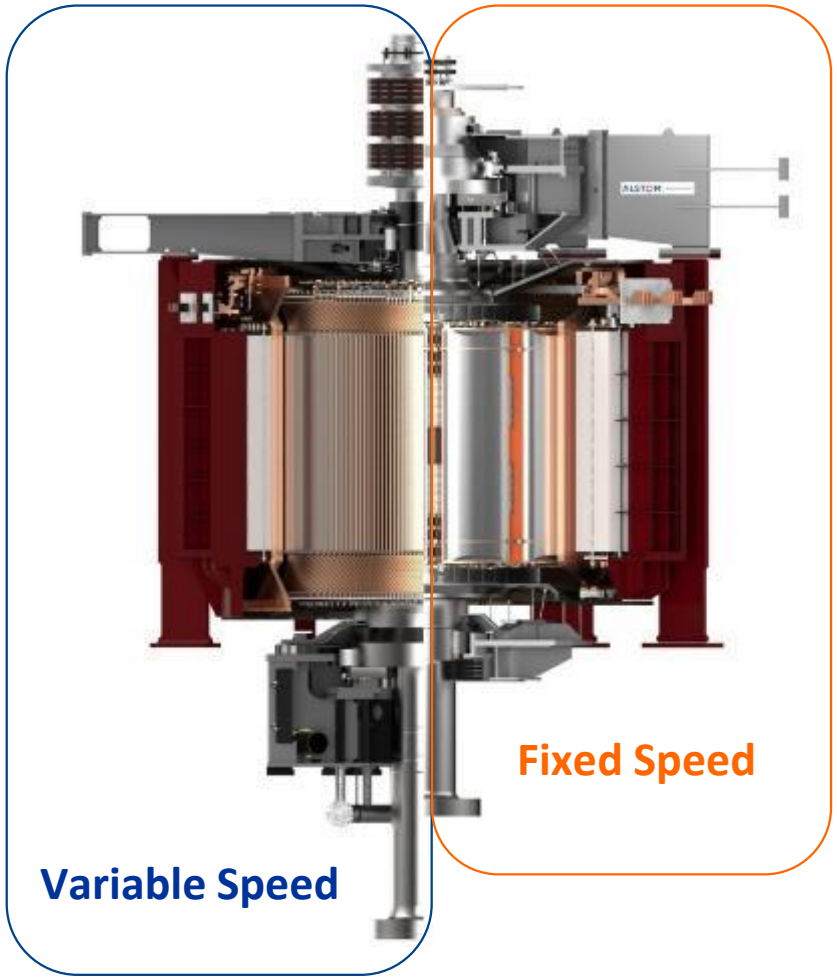
Less than **70 seconds** needed to switch from pump to full load turbine for units up to 400MW

30+% pumping power adjustment when using variable speed technology

Assets with inverters are a reality outside of the US

Fixed speed or variable speed?

Fixed speed = single speed, providing grid stabilization in production mode



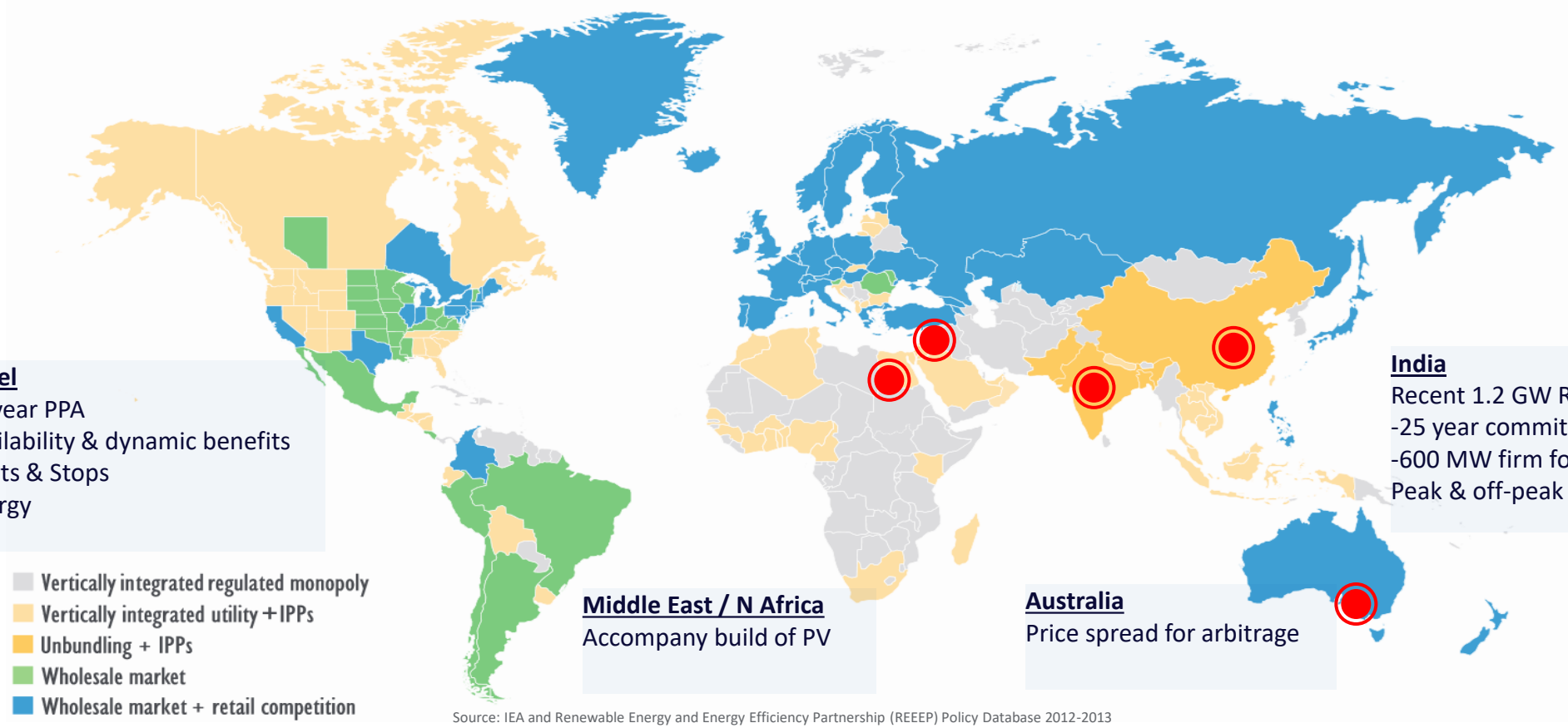
Variable speed = motor generator adjusts turbine speed; provides grid stabilization in production and pumping mode

- ✓ Adjustable power in pump mode eg 30%
- ✓ Wider operating range
- ✓ Faster power adjustment
- ✓ Increased overall efficiencies
- ✓ Improved network stability
- ✓ Better operational behavior
- ⇨ Increased flexibility due to primary frequency control
- ❖ Synthetic inertia, not synchronous (passive)

Pumped Hydro Storage Hot Spots: And why

Energy market liberalization/regulation

Regulated	Partially de-regulated	De-regulated
e.g. China	e.g. U.S.	e.g. Germany



Israel
20 year PPA
Availability & dynamic benefits
Starts & Stops
Energy

Middle East / N Africa
Accompany build of PV

Australia
Price spread for arbitrage

India
Recent 1.2 GW REN auction
-25 year commitment
-600 MW firm for 6 hours
Peak & off-peak tariff

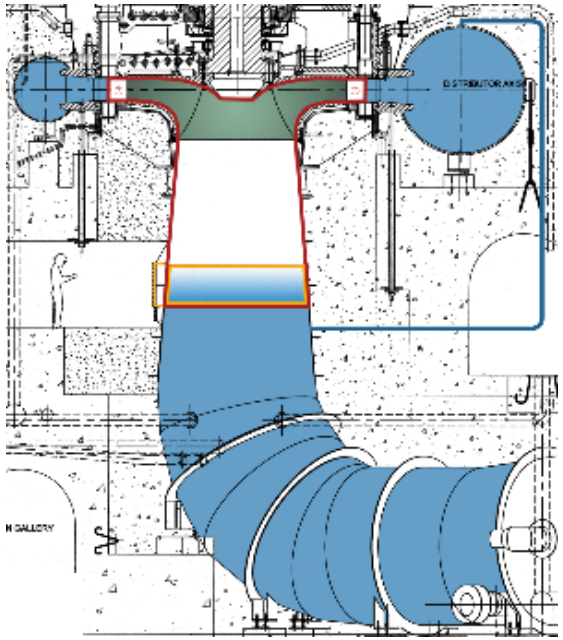
China
Cost of Service
-Capacity Value
-Energy
Grid Asset

Source: IEA and Renewable Energy and Energy Efficiency Partnership (REEEP) Policy Database 2012-2013

A glimpse into the future ? Tasmania, Australia

Fleet (approximative)

- 2300 MW hydro
- 308 MW Wind
- 386 MW Gas
- 100 MW PV (behind the meter)
- HVDC connection (+478 -630 MW)
- Cases of 80% of production from non-synchronous sources



Source : Hydro Tasmania presentation, GE Roadshow June 2017

Conclusion
Hydro is…

- Renewable
- Home-grown
- Dispatchable at scale
- Flexible
- Storage
- Long-lasting (retrofits/upgrades)
- Synchronous gen. & black start
- Competitive