international hydropower association

Pumped Storage Hydropower

The world's oldest battery

Overview

1. Introduction to the IHA
2. Current Status
3. Evolving Need
4. International Forum

   Brief Q&A
5. Looking Ahead
6. Policy and Financial Mechanisms

   Q&A

Voice of Sustainable Hydropower

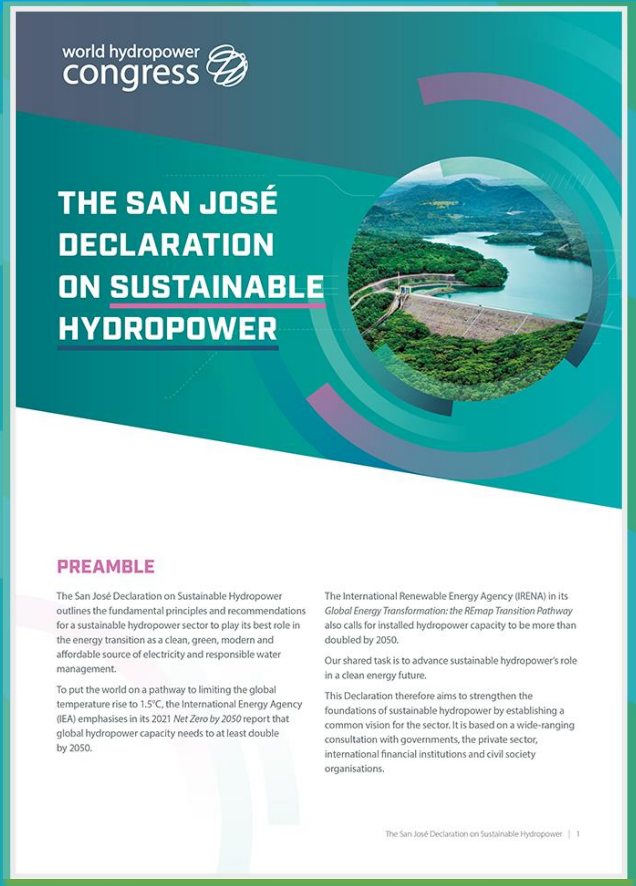
Introduction to the IHA - who we are

The International Hydropower Association (IHA) represents organisations and individuals committed to the responsible and sustainable development and operation of hydropower.

IHA's members share a common purpose: building a world where the world's energy and water needs are supported by sustainable hydropower

Over 100 members active in over 120 countries

hydropower.org



world hydropower congress

THE SAN JOSÉ DECLARATION ON SUSTAINABLE HYDROPOWER

PREAMBLE

The San José Declaration on Sustainable Hydropower outlines the fundamental principles and recommendations for a sustainable hydropower sector to play its best role in the energy transition as a clean, green, modern and affordable source of electricity and responsible water management.

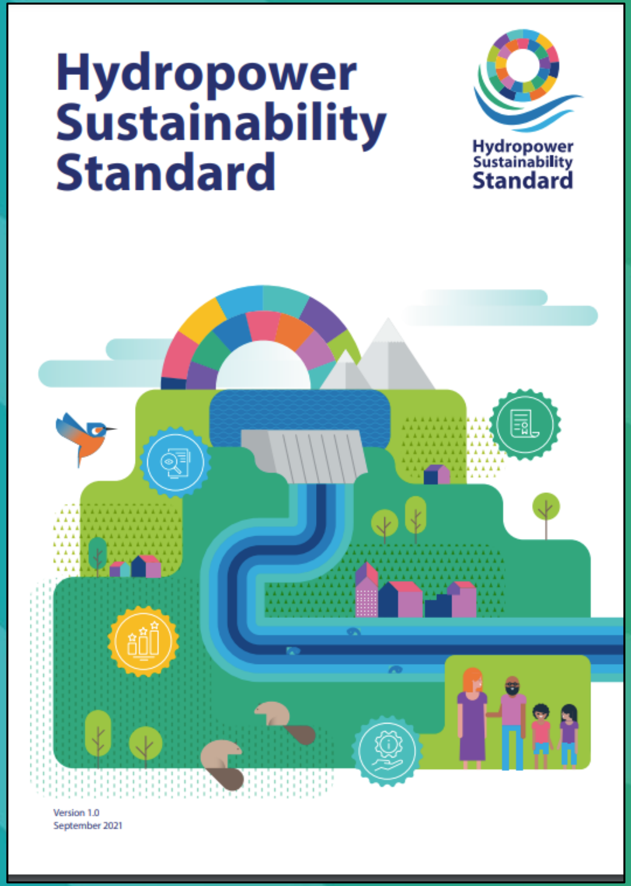
To put the world on a pathway to limiting the global temperature rise to 1.5°C, the International Energy Agency (IEA) emphasises in its 2021 *Net Zero by 2050* report that global hydropower capacity needs to at least double by 2050.

The International Renewable Energy Agency (IRENA) in its *Global Energy Transformation: the REmap Transition Pathway* also calls for installed hydropower capacity to be more than doubled by 2050.

Our shared task is to advance sustainable hydropower's role in a clean energy future.

This Declaration therefore aims to strengthen the foundations of sustainable hydropower by establishing a common vision for the sector. It is based on a wide-ranging consultation with governments, the private sector, international financial institutions and civil society organisations.

The San José Declaration on Sustainable Hydropower | 1



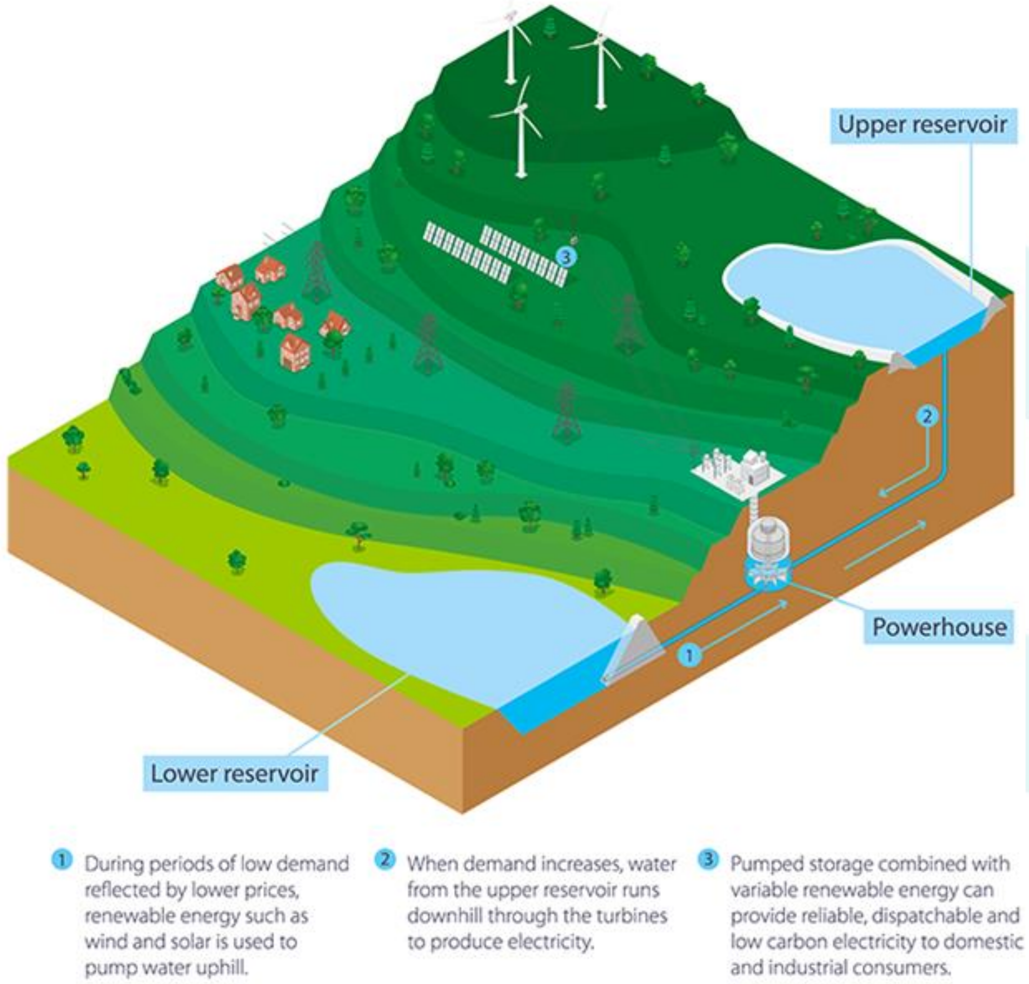
Current Status

Pumped storage hydro – "the World's Water Battery"

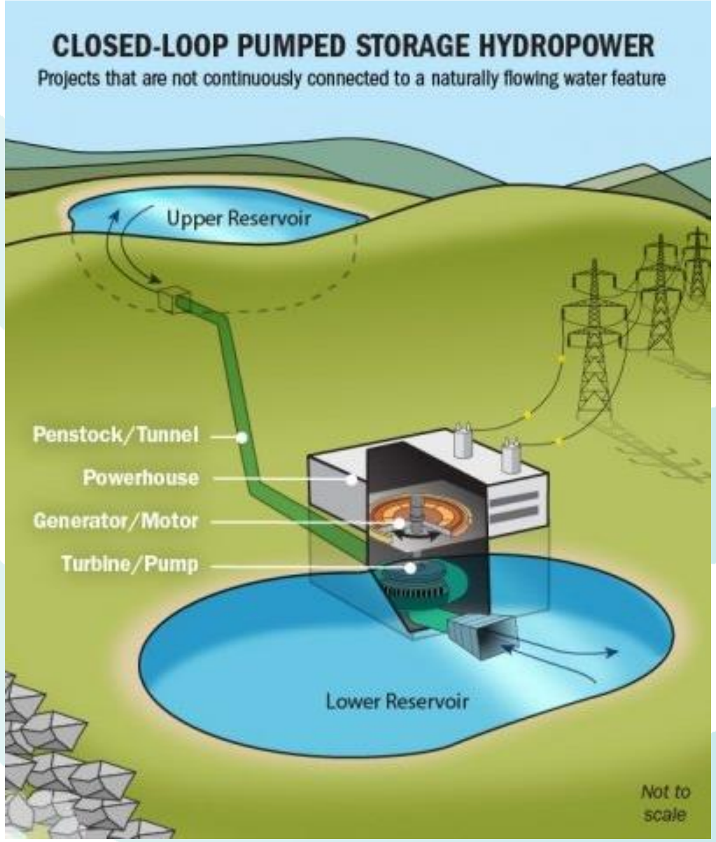
Pumped storage hydropower (PSH) currently accounts for over 90% of storage capacity and stored energy in grid scale applications globally.

The current storage volume of PSH stations is at least 9,000 GWh, whereas batteries amount to just 7-8 GWh.

40 countries with PSH but China, Japan and the United States are home to over 50% of the world's installed capacity.



Closed-Loop PSH and ANU Global Atlas



>600,000 potential sites with 23,000 TWh of storage

http://re100.eng.anu.edu.au/global
https://nationalmap.prod.saas.terria.io/#share=s-tPEnZ4T5NRAYIiLS0E3ftvcAzb

14.57 GW of Closed-loop PSH

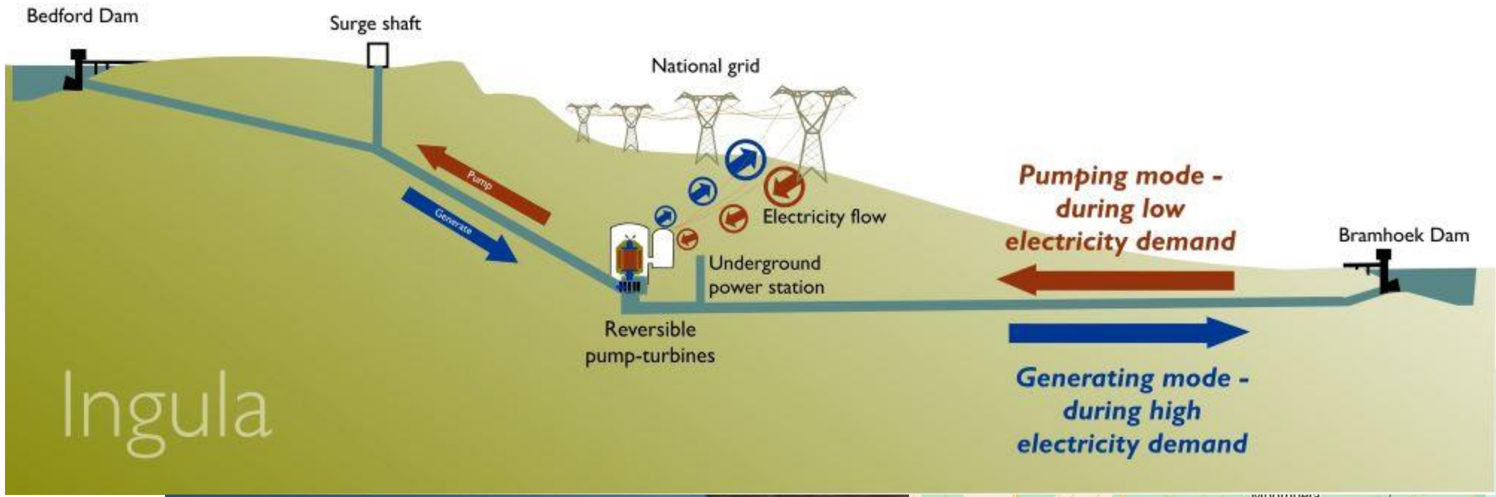
	United States - FERC 2019 Definition
Closed-loop PSH	1. Utilize only reservoirs situated at locations other than natural waterways, lakes, wetlands, and other natural surface water features 2. Rely only on temporary withdrawals from surface waters or groundwater for the sole purposes of initial fill and periodic recharge needed for project operation

Ingula Pumped Storage Scheme, SA

Case study

About:

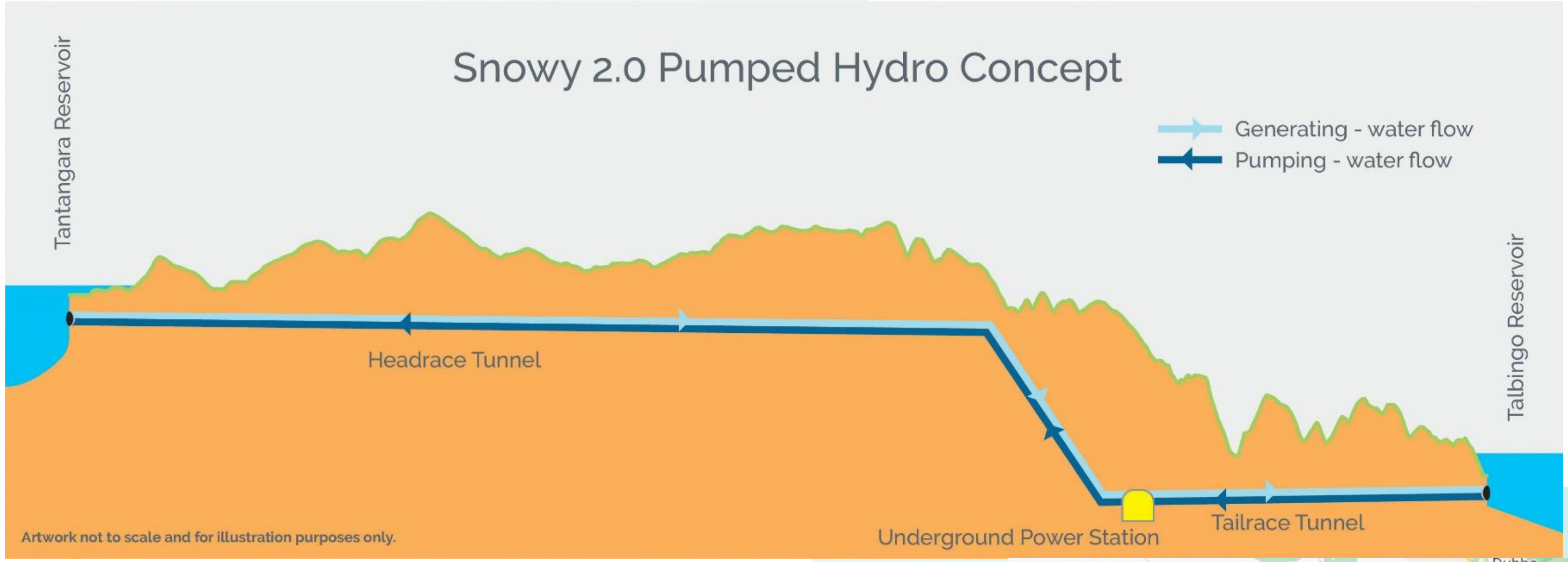
- Commissioned 2016
- 14th Largest PSH in world
- 16 hours of continuous generation (21,312 MW/h of storage)
- 1,332 MW (4x333 MW units)
- Provides peaking loads to react quickly to changes in demand



Sustainability:

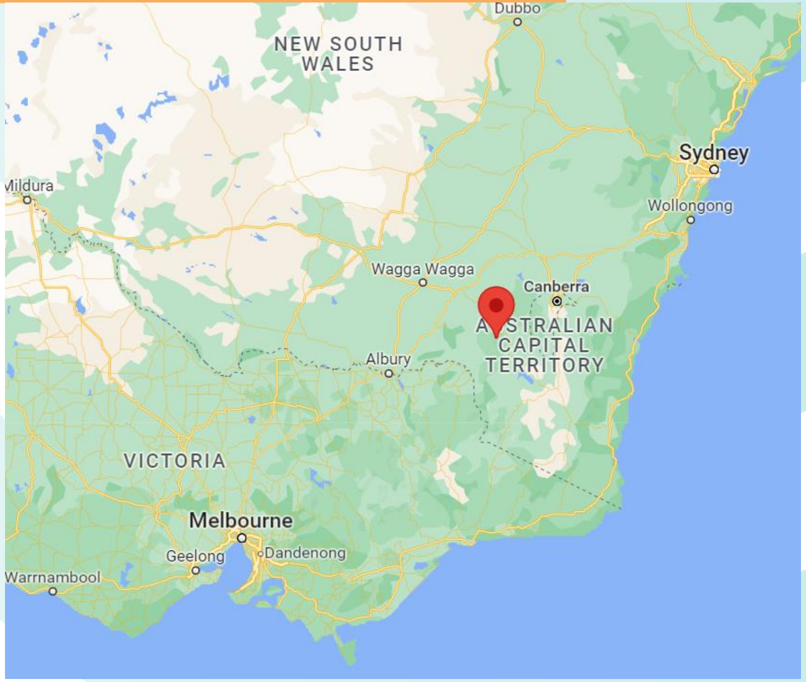
- Eskom has designated the surrounding area as a conservation area.
  - 1000ha of wetland protected
  - 600+ha of alien vegetation eradicated
  - 110+km of firebreaks prepared annually
  - 100+km of historical erosion ditches being rehabilitated
  - 335+ species of bird seen at Ingula
  - 40+ species of mammal seen at Ingula
  - 28+ species of reptile seen at Ingula

Snowy 2.0
Case Study



Why Snowy?

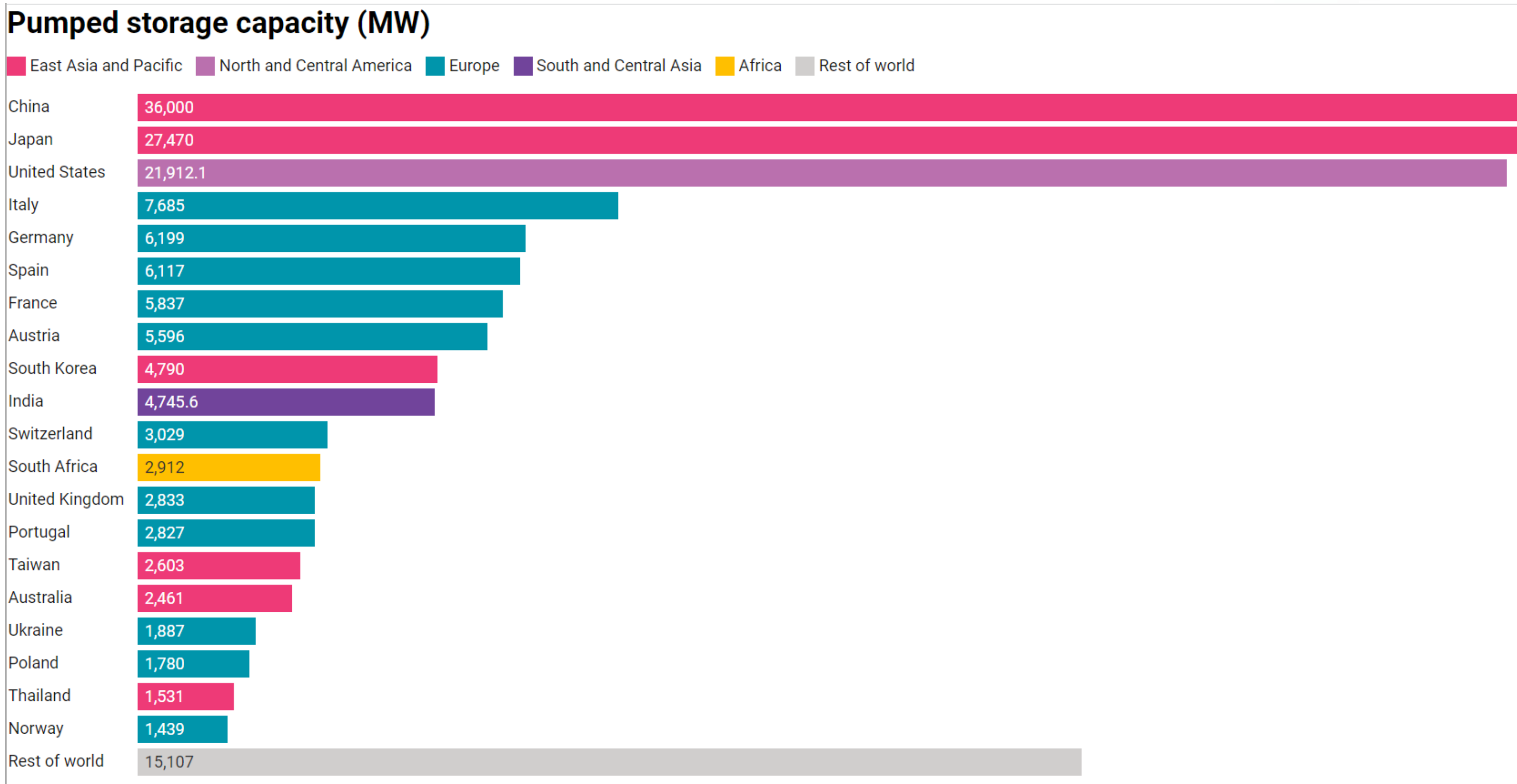
- To underpin Australia's energy transition by combining on-demand hydro energy with wind and solar.

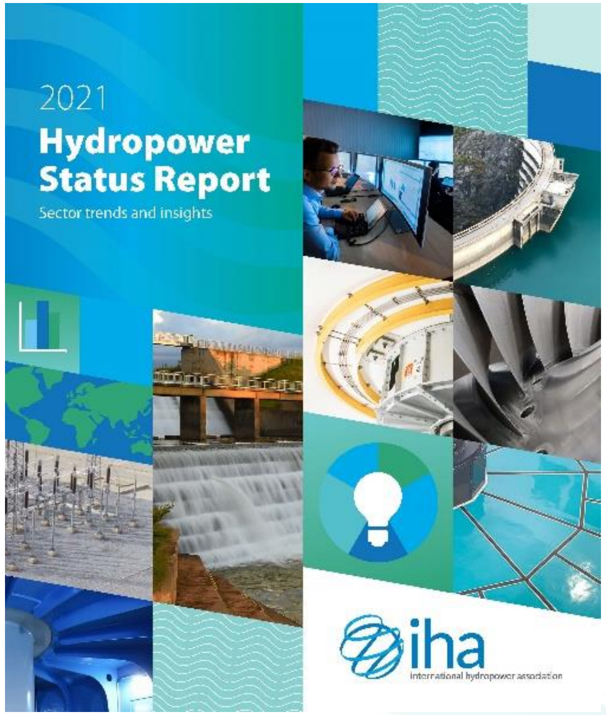


Solution

- Snowy 2.0 will link two existing dams – Tantangara and Talbingo – through 27km of tunnels and build a new underground power station.
- It has the capability to run for more than seven days continuously before it needs to be 'recharged'. Snowy 2.0 also has a 100-year design life.
- It is expected to be completed in 2026 and deliver 2,000 MW of on-demand energy generation and 350,000MW/h of large-scale storage

Global Breakdown

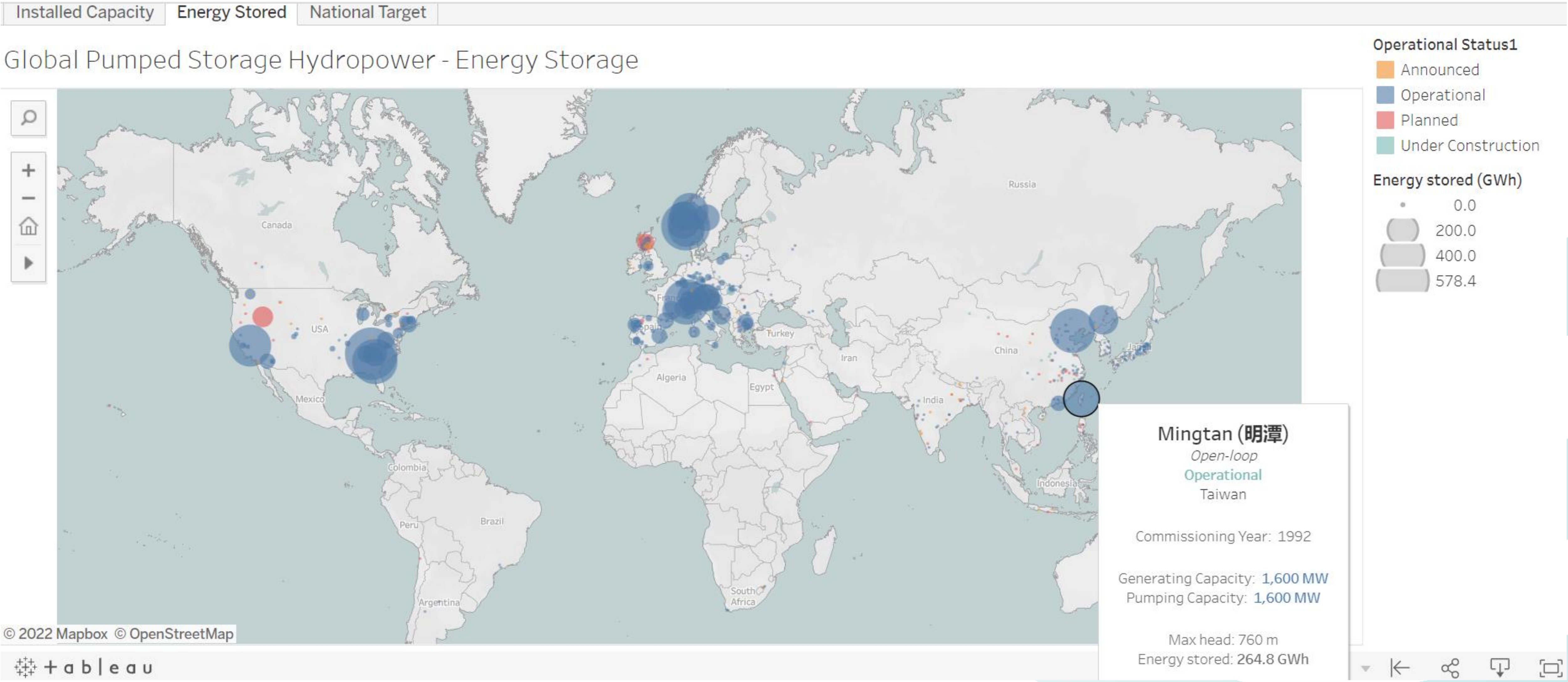




PSH increased by 4.7 GW in 2021

3% of global installed capacity 2020

Pumped storage tracking tool

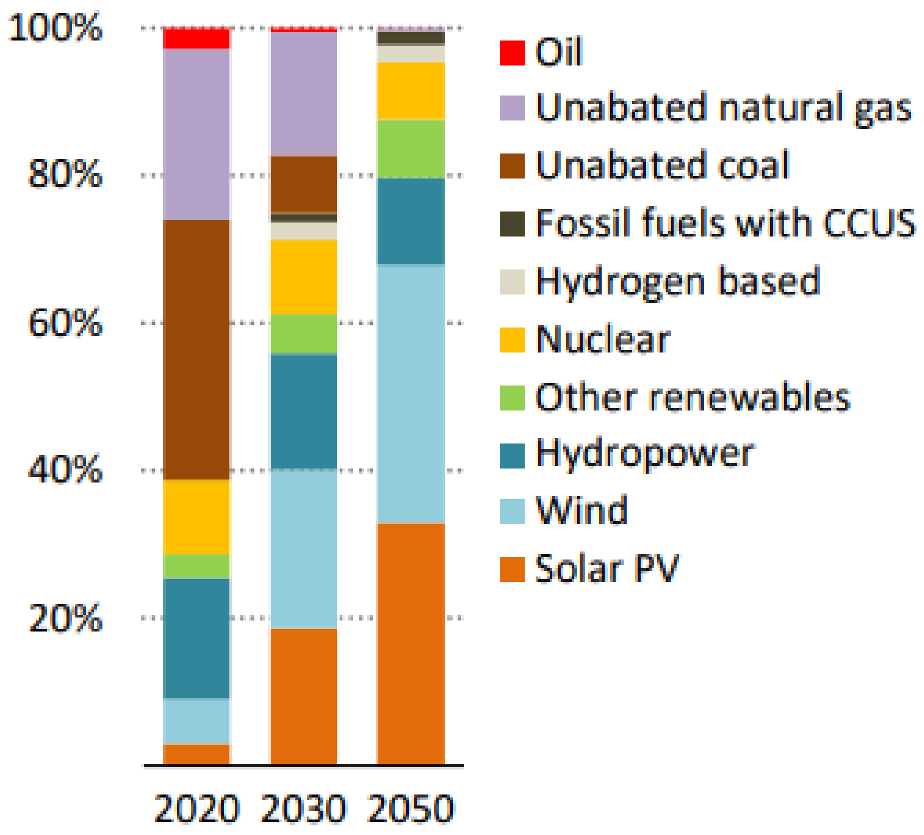


Evolving Need

PSH's role in clean energy transition

Pumped storage hydropower (PSH) will play an increasingly important role in the clean energy transition:

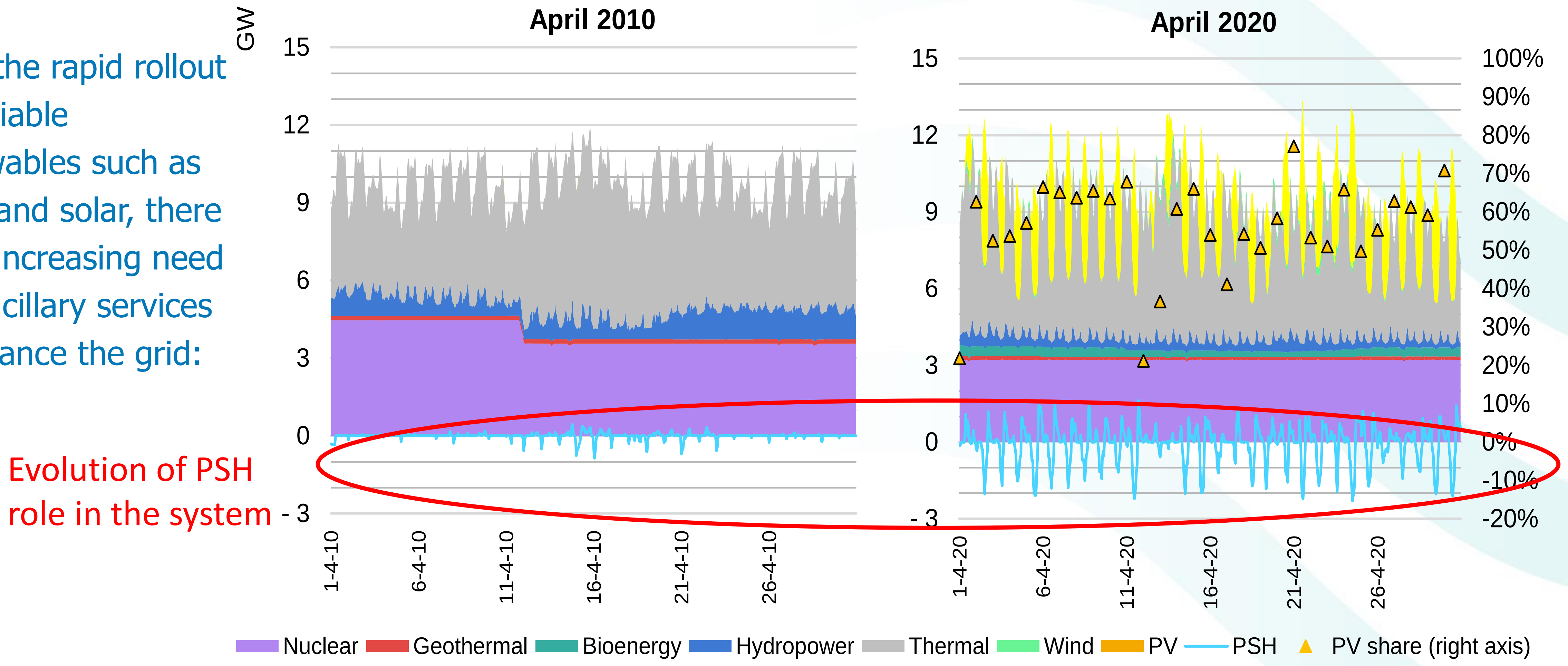
- **supporting wind and solar growth** by compensating for their variability and firming their output power;
- providing **large energy storage capacity** to reduce curtailments;
- providing **inertia and other ancillary services** to stabilise electricity grids;
- reducing the need for **operating reserves** from high carbon coal and gas; and
- providing **black start** capability to restore the power system after a blackout.



Global electricity generation by source, Net Zero scenario
(IEA 2021 – Net Zero by 2050)
2050- 33,000GW total capacity

Increasing need for flexibility

With the rapid rollout of variable renewables such as wind and solar, there is an increasing need for ancillary services to balance the grid:



- **Spinning and fast ramping**
- **Frequency control**
- **Black Start**
- **Rotating inertia**
- **Reactive power control**

Evolution of PSH in flexibility and storage services between 2010 and 2020 in Kyushu Island, Japan (ref. IEA, 2021)

Reduced system inertia

Mechanical inertia provides an important "**self-healing**" stabilisation effect to the grid:

- spinning generators **resist drops in frequency** when a power plant or transmission fails, and this mechanical inertia, or stored kinetic energy, limits the gradient and the total drop of the grid frequency.

Thermal power plants are being phased out and power systems with high shares of VRE will lose a substantial part of their mechanical inertia.

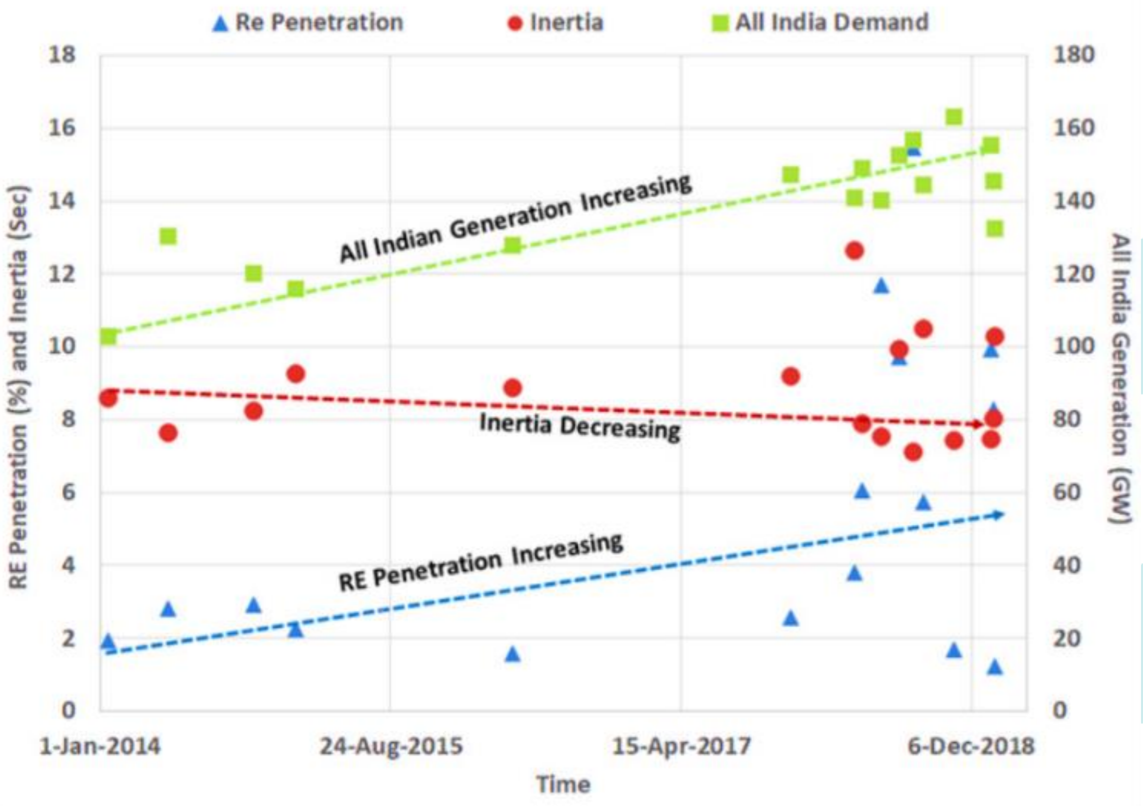


Figure: Inertia and renewables penetration in India, 2014-2018 (IEA, Renewables Integration in India 2021).

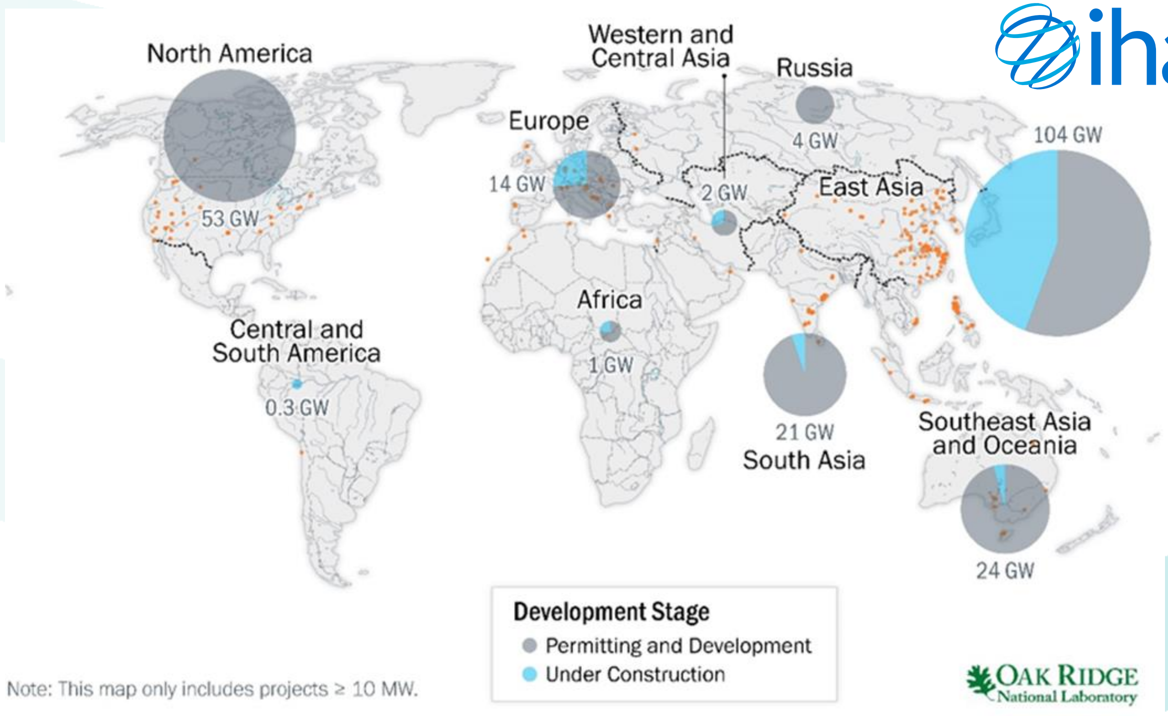
PSH development under pressure

- Recent developments are mainly driven by **China, led by government / public utilities**.

- Other projects recently commissioned or under construction include Europe, Asia, India, Israel, Australia, Morocco, or United Arab Emirates.

- Uncertainty around the business model (incomplete valuation) + long lead-time development

➔ Very little private sector-led or financed PSH capacity



PSH project development pipeline by region and development stage

International Forum

International Forum on Pumped Storage Hydropower

Context of the Forum

A government-led multi-stakeholder platform to help address the key challenges facing pumped storage development

This 18 month initiative brought together:

- Governments, with the U.S. Department of Energy the lead sponsor
- Multilateral bodies – banks and energy bodies
- Over 80 partner organisations from industry, finance community, academia and NGOs

IHA was the secretariat to the wider Forum, the Steering Committee and the three working groups.

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Policy & Market Frameworks

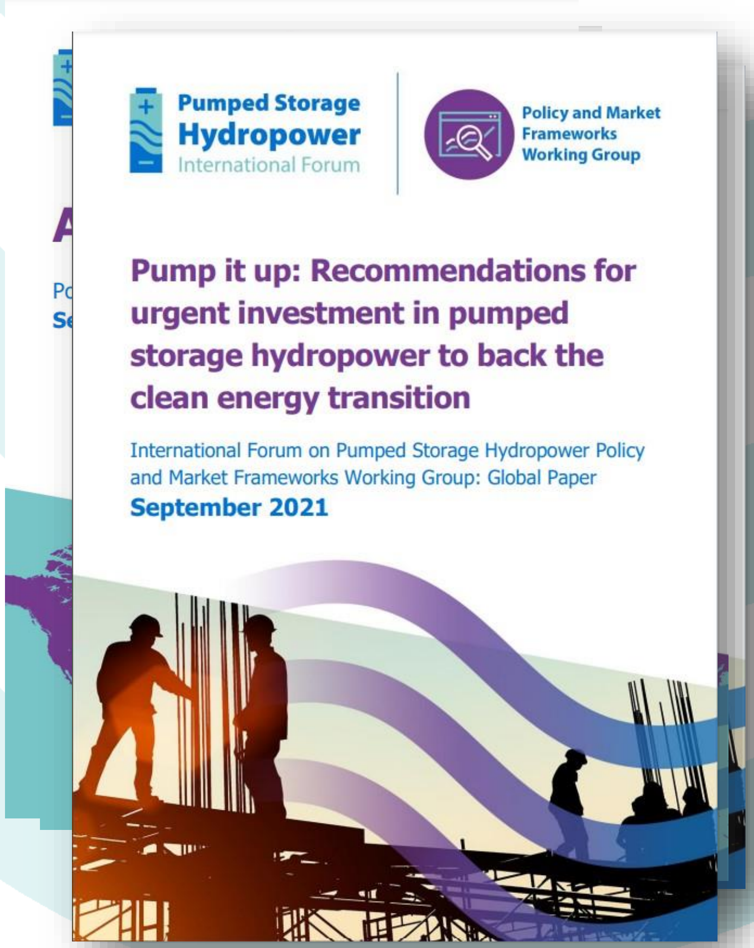
Pumped Storage Hydropower International Forum

- Global position paper
- 15 Country and regional papers

Led by:
GE Renewable Energy

Seven recommendations for action

1) Assess long-term storage needs now, so that the most efficient options, which may take longer to build, are not lost.
2) Ensure consistent, technology neutral comparisons between energy storage and flexibility options.
3) Remunerate providers of essential electricity grid, storage, and flexibility services.
4) Licensing and permitting should take advantage of internationally recognised sustainability tools.
5) Ensure long-term revenue visibility with risk sharing to deliver the lowest overall cost to society.
6) Assess and map for PSH potential existing hydropower assets and prospective sites.
7) Support and incentivise PSH in green recovery programmes and green finance mechanisms.



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Sustainability

- Working Paper on Sustainability of PSH

Pumped Storage Hydropower International Forum

Key findings

1) PSH should be considered as a key enabler of the clean energy transition, alongside other energy storage technologies.

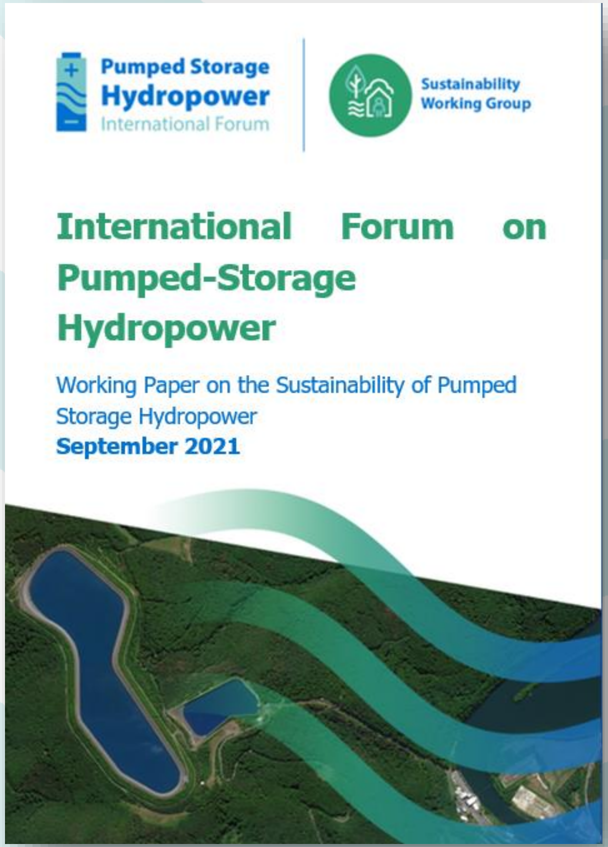
2) Three level assessment framework: adopt system needs assessment; technology options assessment; and project optimisation to avoid, minimise and mitigate social and environmental impacts.

3) PSH impacts are site-specific. The internationally recognised Hydropower Sustainability Tools can navigate these nuances.

4) Use of Life Cycle Analysis on PSH requires specific attention on the boundaries and functional units of the power system (e.g. the underlying energy mix) to avoid misleading conclusions.

5) Consider **one-time or permanent local benefits of PSH** in sustainability assessment.

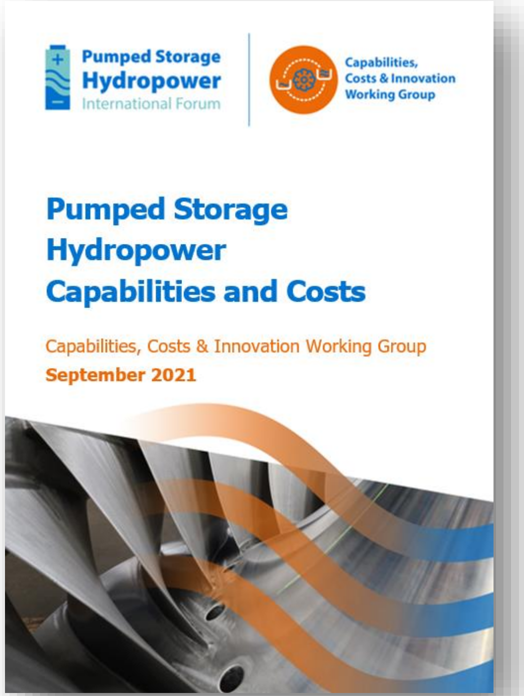
Led by:
EDF Hydro



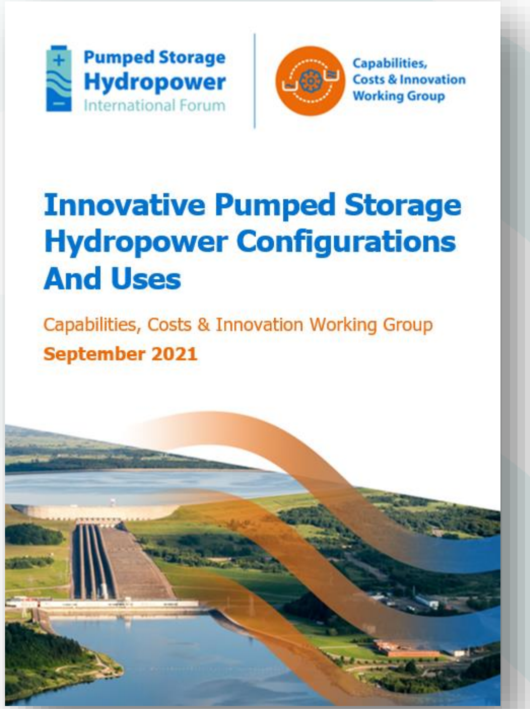
Capabilities, Costs & Innovation

Deliverables

PSH Capabilities and Costs



Innovative PSH Configurations and Uses



Interactive online map on global PSH potential

Developed by Dr. Julian Hunt, Research Scholar at IIASA

To learn more, please visit:

pumped-storage-forum.hydropower.org

hydropower.org

Capabilities, Costs & Innovation

Energy Storage Comparison (4-hour storage)

Pumped Storage Hydropower International Forum

Comparison metrics

	Type of energy storage	Pumped Storage Hydro	Li-Ion Battery Storage (LFP)	Lead Acid Battery Storage	Vanadium RF Battery Storage	CAES compressed air	Hydrogen bidirect. with fuel cells
		100 MW / 4hr	100 MW / 4hr	100 MW / 4hr	100 MW / 4hr	100 MW / 4hr	100 MW / 10hr
Technical Capabilities	Technical readiness level (TRL)	9	9	9	7	7	6
	Inertia for grid resilience	Mechanical	Synthetic	Synthetic	Synthetic	Mechanical	no reference
	Reactive power control	Yes	Yes	Yes	Yes	Yes	Yes
	Black start capability	Yes	Yes	Yes	Yes	Yes	Yes
Performance Metrics	Round trip efficiency (%*)	80%	86%	79%	68%	52%	35%
	Response time from standstill to full generation / load (s*)	65...120 / 80...360	1...4	1...4	1...4	600 / 240	< 1
	Number of storage cycles (#*)	13,870	2,000	739	5,201	10,403	10.403
	Calendar lifetime (yrs*)	40	10	12	15	30	30
Costs 2020	avg. power CAPEX (USD/kW*)	2,046	1,541	1,544	2,070	1,168	3.117
	avg. energy CAPEX (USD/kWh*)	511	385	386	517	292	312
	avg. fixed O & M (USD/kW/yr*)	30	3.79	5	5.9	16.2	28.5
	effective CAPEX (USD/kW based on PSH life of 80 years and 6% discount rate**)	2,710	4,570	5,070	8,370	3,340	8,900
Estimated costs 2030	avg. power CAPEX (USD/kW*)	2,046	1,081	1,322	1,656	1,168	1.612
	avg. energy CAPEX (USD/kWh*)	511	270	330	414	292	161
	avg. fixed O & M (USD/kW/yr*)	30	3.1	4.19	4.83	16.2	28.5
	effective CAPEX (USD/kW based on PSH life of 80 years and 6% discount rate**)	2,710	3,210	3,920	4,910	3,340	4,620

*Source: US DOE, 2020 Grid Energy Storage Technology Cost and Performance Assessment

**considering the value of initial investment at end of lifetime including the replacement cost at every end-of-life period

Capabilities, Costs & Innovation

17 PSH Innovations featured

Pumped Storage Hydropower International Forum

Category	Name of Technology	Organisation
Further PSH potentials	Location Agnostic Pumped Storage	McWilliams Energy
	Use of Modern Tunnel Boring Machines for Underground Pumped Storage	Nelson Energy
	Saltwater PSH for Small Island Developing States	IHE-Delft
	Off-river closed-loop PSH	ANU
	Geomechanical PSH	Quidnet Energy
Retrofitting & upgrading	Obermeyer Reversible Pump Turbine	Obermeyer Hydro
	Retrofitting PSH on open pit mine	Stantec
	PSH utilising underground mine	AFRY
	Retrofitting existing hydropower reservoirs	McWilliams Energy
	PSH operating range extension – Alqueva	GE Renewable Energy, EDP
	Double-fed Induction Machines in Hydraulic Short Circuit Operation – Frades 2	EDP
	Hydraulic Short Circuit at High Head PSH – Grand Maison	EDF
Hybrid systems	Solar PV hybrids	World Bank ESMAP, ISL, IIT Roorkee
	Hybrid Renewable Modular Closed-Loop Scalable PSH System	Liberty University
	Hybrid PSH - Battery Storage (HPBS)	Fluence, SuperGrid Institute, Idaho National Laboratory, EPFL
	Integrated Pumped Hydro Reverse Osmosis Clean Energy System (IPHROCES)	Oceanus
	Thermal PSH	TU Graz

Question and Answer Period

Looking ahead

Deployment Targets and Innovation

Mines – a Golden Opportunity

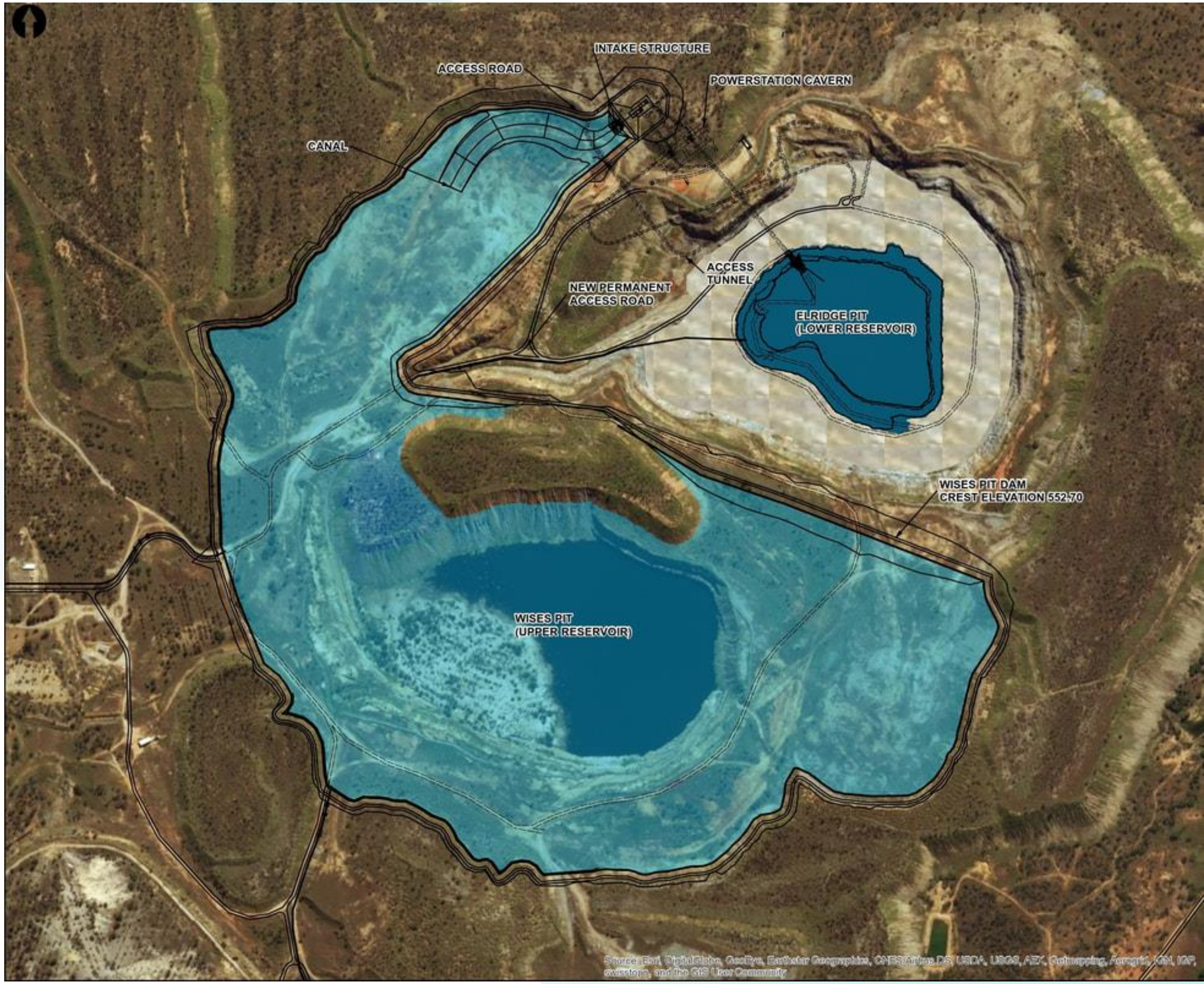
Case study: Kidston Stage Two

About:

- First PSH to utilise an abandoned gold mine and developed by Private Sector
- Integrated and co-located with the Kidston 270MW Solar Project.
- Project specifications:
  - 250MW for 8 hours (2,000MWh)
  - <30 sec. ramp up time
  - 218m max head
- Construction started in 2021 and is expected to be commissioned in 2024
- Re-use of existing mines = lower CAPEX
- Kidston is creating 900 direct jobs, and will help the State achieve its Renewable Energy Target of 50% by 2030.

Other examples:

- Thyssenkrupp Uhde Africa and Wismut GmbH announced a pre-feasibility study for an underground PSH with a South African Mining Company.

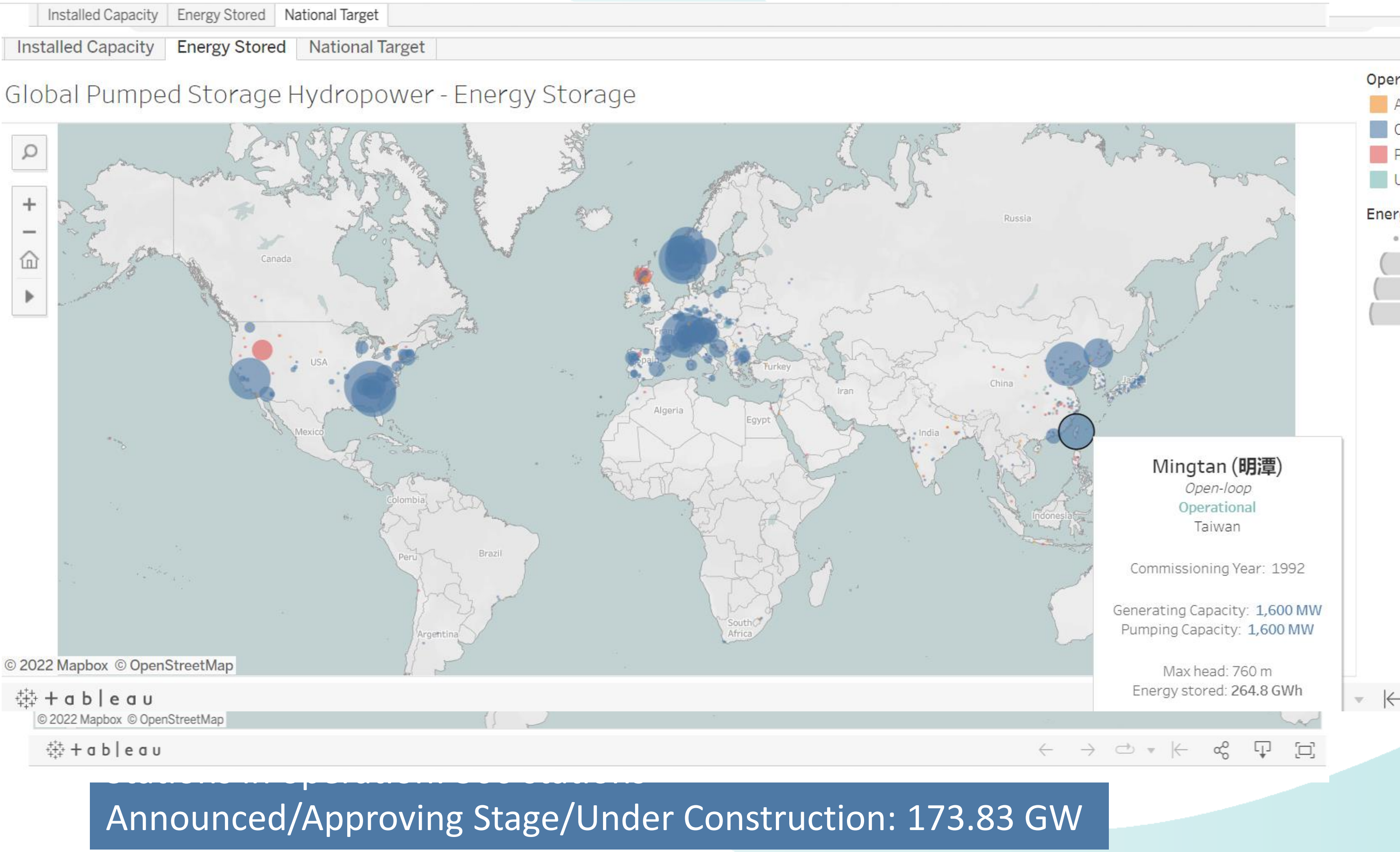


Pumped storage tracking tool

The pumped storage project tracking tool (https://www.hydropower.org/hydropower-pumped-storage-tool) will shortly be updated to include:

- New projects added since the tool launched in 2019
- Country level summary
- National level targets where we have them (2030 and 2050)

Note that this tool is separate to the *resource potential* map developed by Dr. Julian Hunt, at IIASA (https://pumped-storage-forum.hydropower.org/resources/pumped-storage-potential-map)



Complementary Goals

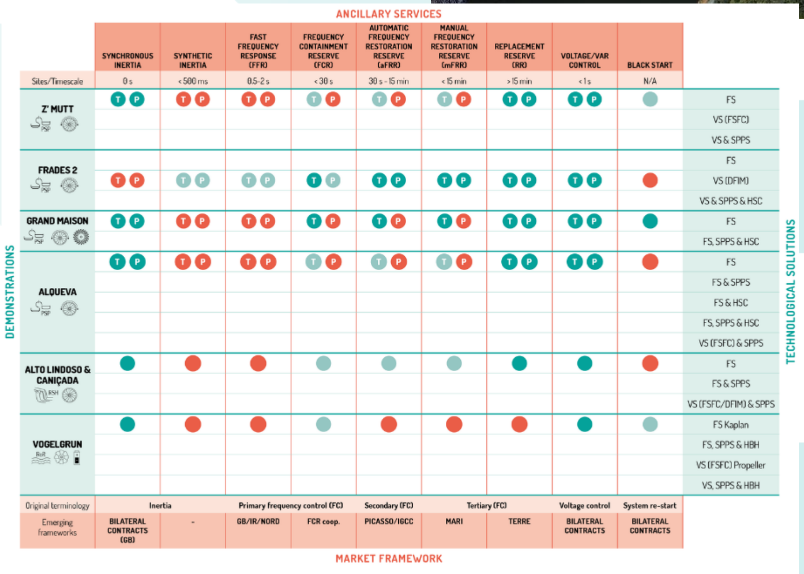
PSH and VRE Targets

Country	National PSH target added by 2030 (GW)	National Renewable Energy Target
China	90	1,200 GW of solar and wind in 2030
USA	16.2	100% clean electricity grid by 2035 - 30GW of offshore wind by 2030 ; 30 GW of Solar per year by 2025 and 60 GW per year from 2025-2030.
India	4.44	achieve 175GW of variable renewable generation from solar, wind, biomass, and small hydro by 2022 and 500 GW by 2030
Spain	3.5	more than 50 GW of wind and 39.2GW of solar by 2030.
Vietnam	2.4	18.6 GW of solar and 18.0 GW of wind by 2030.
Thailand	1.61	Non-hydro renewables in the electricity reach 22% in 2030
Lesotho	1.2	hydropower, solar, and wind reach 75% renewable generation by 2022.
Russia	0.8	
Greece	0.75	35% of energy and 61% of electricity from renewables by 2035
Sri Lanka	0.6	70% of renewable energy installed capacity by 2030

XFLEX HYDRO to demonstrate hydropower's flexibility

- The European Commission has launched an €18 million initiative – Hydropower Extending Power System Flexibility (XFLEX HYDRO) – to run until 2023. The project is being delivered by a consortium of 19 industry partners, and aims to enhance hydropower's potential in modern power markets. Visit www.xflexhydro.net

19 project partners



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Policy and Financial Mechanisms

Policy mechanisms

Examples of national policies that might encourage hydropower

Country/Jurisdiction	Policy/mechanism
India	Hydropower mandates/attribution
China	Energy storage targets
United States	Tax credits; Capacity market (CM) payments
Australia (New South Wales)	Long-term pull-in mechanism
United Kingdom	Consideration of a cap-and-floor mechanism; Regulated Asset Base models
Israel	Availability and performance contracts for storage and flexibility services
Nepal	Concession on lease rental rates; Capital subsidy on equipment required for project construction; Bank guarantee facility or concession on customs duty, foreign currency, hedging facility; PPP law.
Chile	Direct subsidies into pre-feasibility and pre-investment projects for low-carbon projects.
Spain	New pay-as-bid model for capacity market; €684M for storage and smart grids.

Financial Mechanism: Revenue visibility

Case study: Israeli Electric Corporation

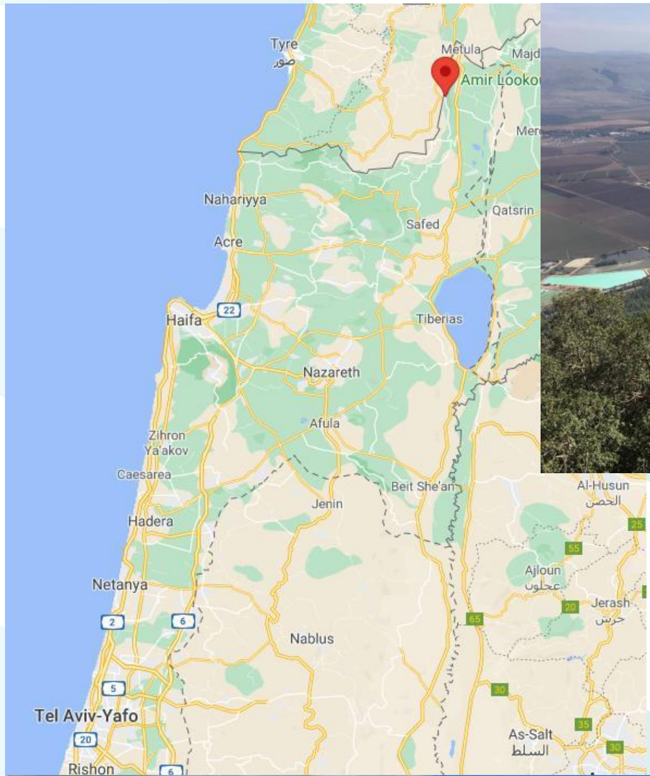
About:

- IEC identified a need for 800MW of energy storage (5% of demand of 18 GW).
- Developed a payment mechanism with a remuneration structure intended to ensure private financing and development of PSH projects

Structure:

Payment is based on plant availability over 18-20 years. Three-part payment scheme consists of following revenue streams:

1. Primary source of revenue: An availability payment which forms the bulk of revenue and require the plant to be available for a minimum time during a year. In addition, an availability requirement is passed on to the equipment manufacturer, supplying plant availability guarantees through a long-term operations and maintenance contract. This payment also includes bonus payments for dynamic benefits including ramp rates, pumping to generation switching timeframes, start-up and shutdown speeds, etc.
2. Payment for energy.
3. Start up and shut down payments based on how often the plant is operated.



The Manara Pump Storage Project will have an installed capacity of 156 MW (single 156 MW unit).

Gilboa 300 MW PSH became operational in 2020

Decision-makers can implement policy change in a number of areas to encourage hydropower investment

Finance

Recognise additional benefits of hydro e.g. flexibility
Provide long-term visibility of revenues
Remuneration for ancillary services

Sustainability

Widespread adoption of Hydropower Sustainability Standard

Regulation

Proportionate, streamlined license/permit processes to rapidly scale up the needed hydropower

Maximise existing infrastructure

Invest in modernization
Assess scope for retrofitting

Thank you

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Questions?

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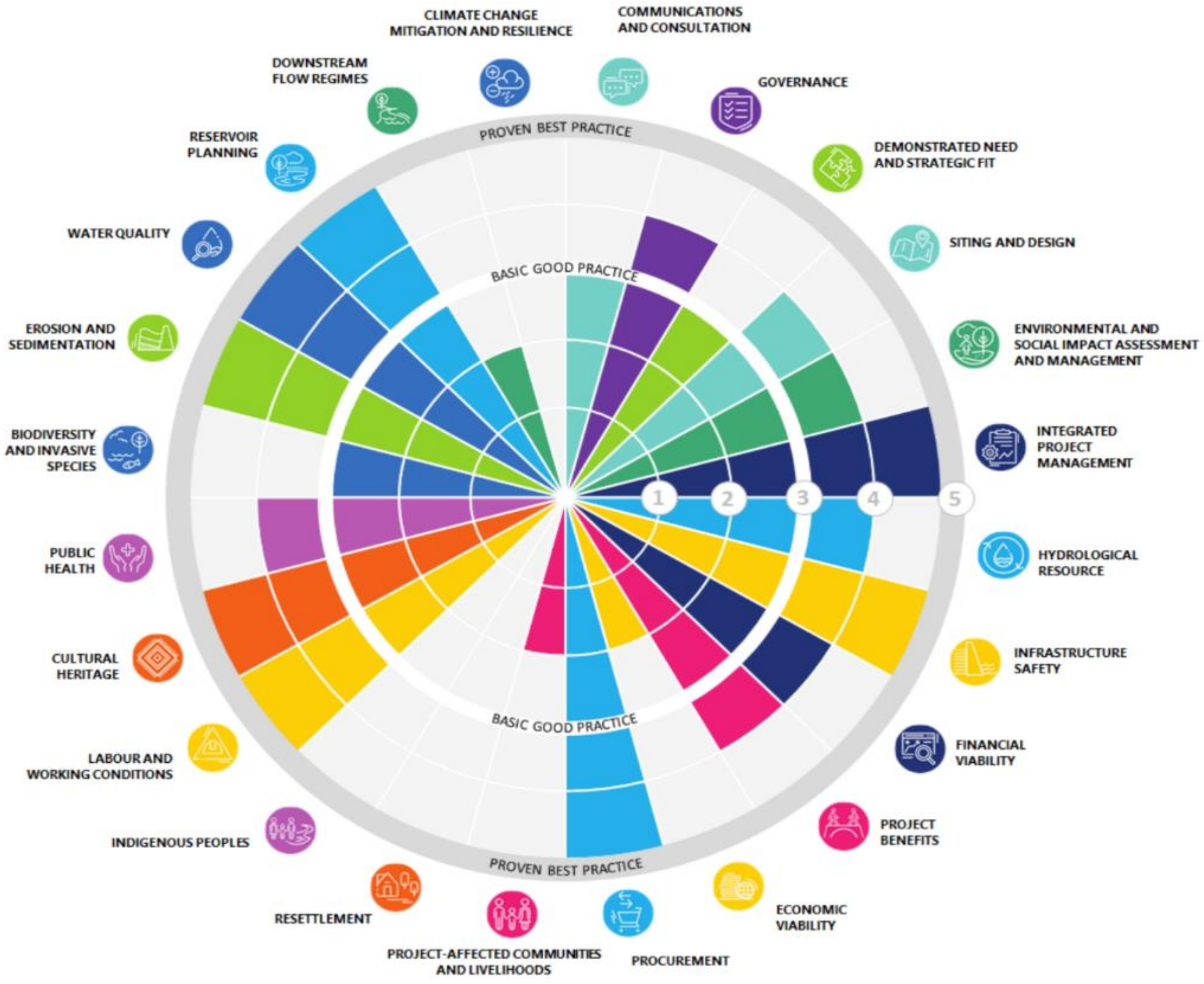
Existing Sustainability Tools for Hydropower (HST suite developed by IHA) are adequate for PSH technology & projects

Example of **HSAP applied to Versetz PSH in Kaunertal Expansion Project (Austria)**



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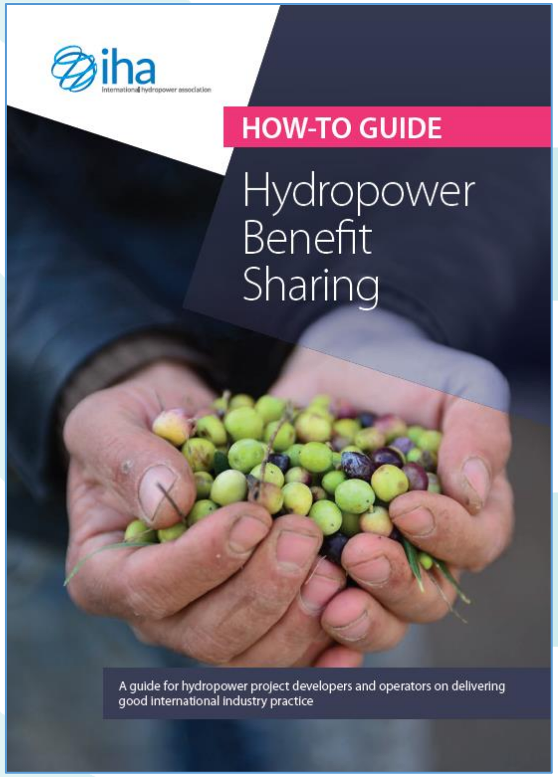
PSH projects can generate one-time or permanent Local Benefits of various nature which must be considered in their sustainability profile assessment



IHA How-to Guide

"Hydropower Benefit Sharing" (2019)

Challenge: Intermittency
ANU – South Australian Grid Case Study