

ENERGY STORAGE

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ENERGY
TRANSITION
PARTNERSHIP

Agenda

01	Why do we need storage?	03
02	Pumped hydro energy storage	07
03	Battery storage	23
04	Hydrogen	35



01

WHY DO WE NEED STORAGE?



Solar and wind have won the energy race

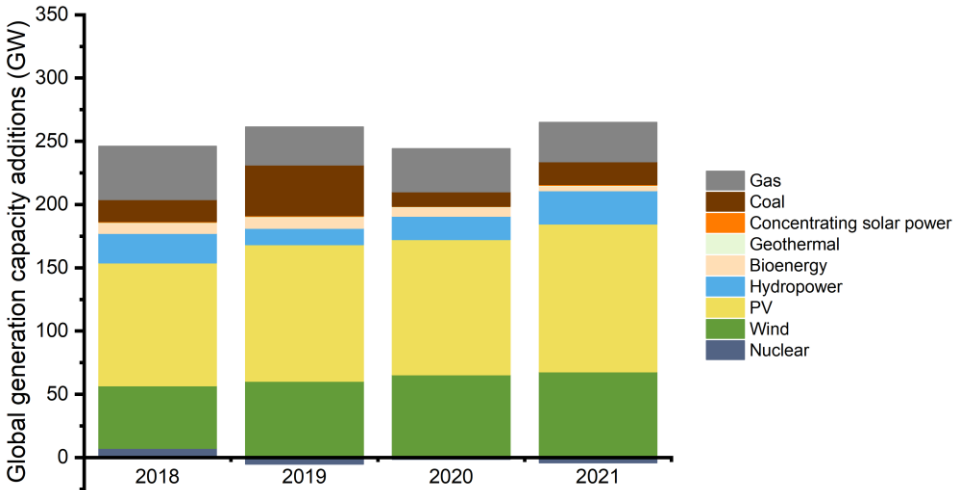
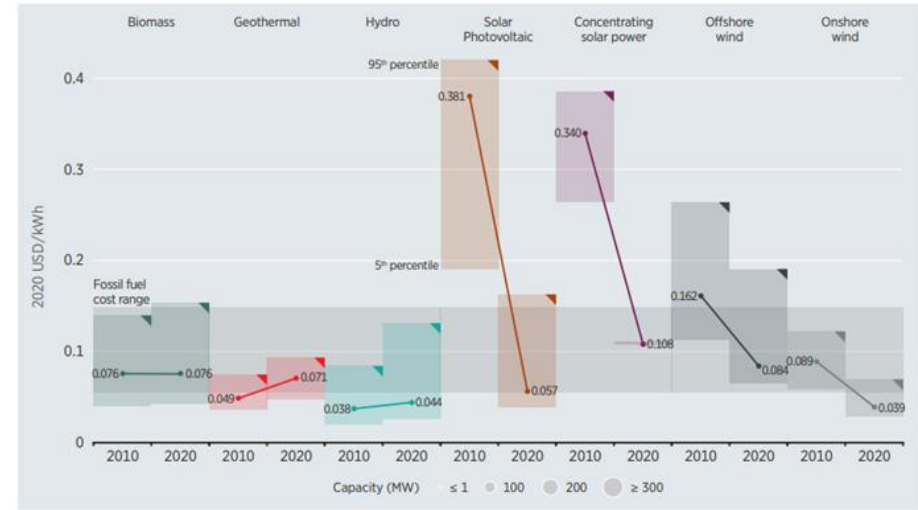


Figure ES.2 Global LCOEs from newly commissioned, utility-scale renewable power generation technologies, 2010-2020



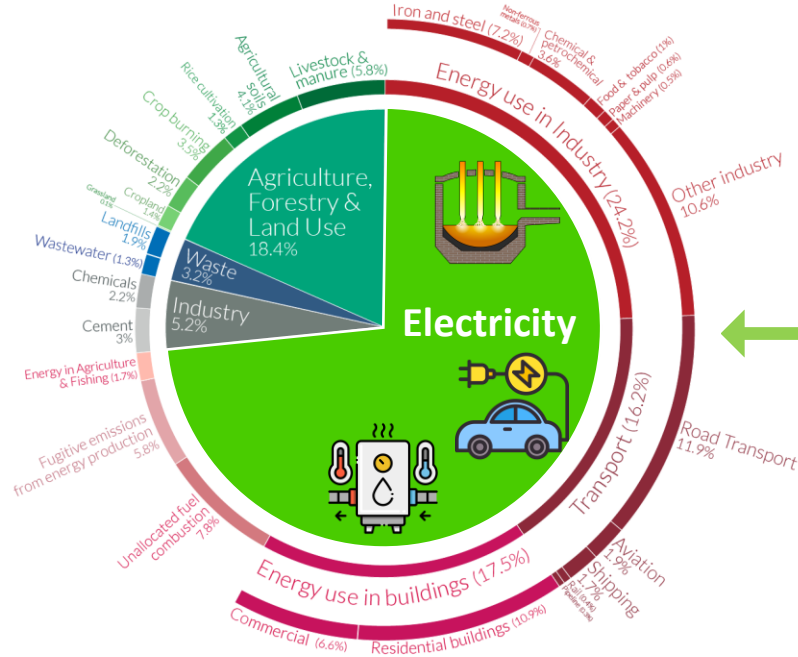
- Solar PV and wind account for > 50% of global net generation capacity additions
- Significant and continued cost reductions: cheaper than new coal and gas, and cheaper than 80% of global operating coal

¾ of global emissions are energy-related

Global greenhouse gas emissions by sector

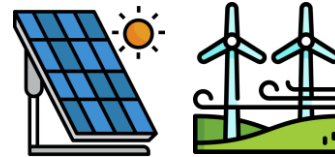
This is shown for the year 2016 – global greenhouse gas emissions were 49.4 billion tonnes CO₂eq.

Our World
in Data



Pathway to decarbonized energy:

- 100% renewable electricity
- Electrified transport, heat and industry



OurWorldinData.org – Research and data to make progress against the world's largest problems.

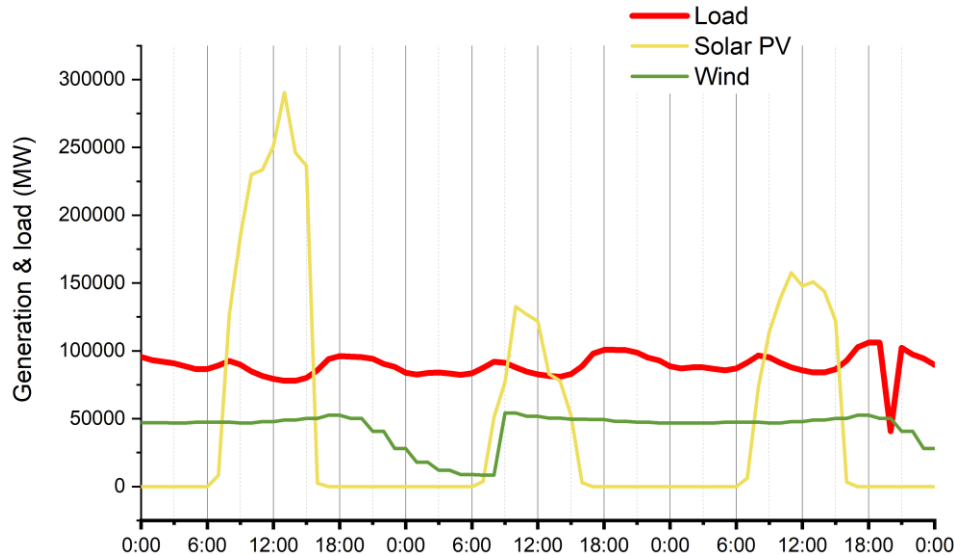
Source: Climate Watch, the World Resources Institute (2020).

Licensed under CC-BY by the author Hannah Ritchie (2020).



Balancing of variable solar and wind generation

Challenge: the variable nature of solar and wind



Balancing solar PV and wind:

- **Flexible generation** (hydroelectricity, gas, bio etc.)
- **Storage** (pumped hydro, battery etc.)
- **Interconnection**
- **Demand response**

The lowest-cost solution is often an optimal combination of several measures.

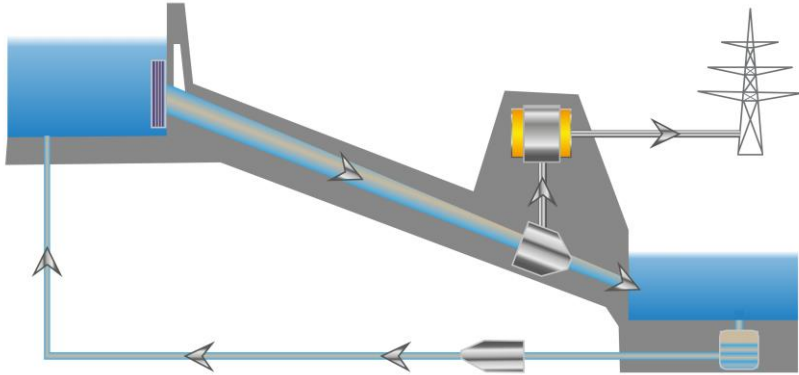


02

PUMPED HYDRO ENERGY STORAGE



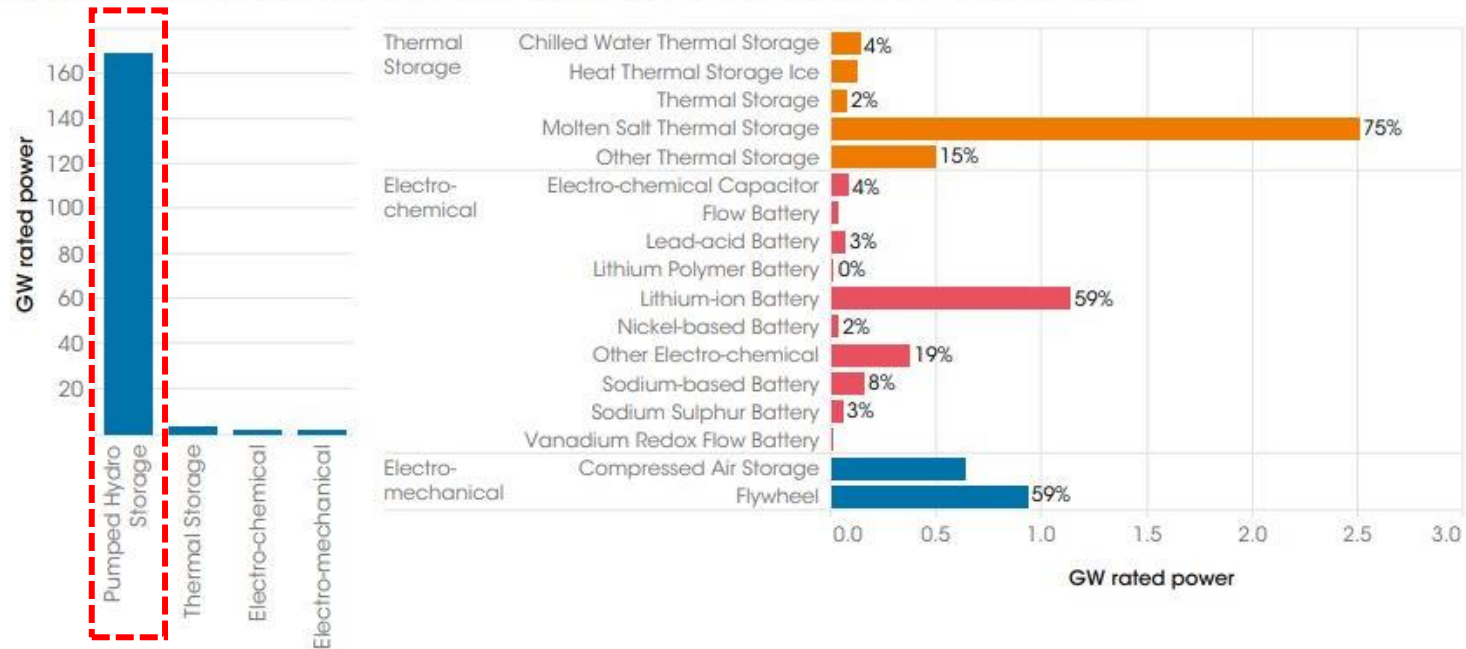
How does pumped hydro work?



- Two reservoirs with different altitudes (“head”)
- Connected by a pipe or tunnel
- Charging: water pumped from lower reservoir to upper reservoir when generation > demand
- Discharging: water flows from the upper reservoir to the lower reservoir through a turbine when demand > generation

Pumped hydro dominates the storage market

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



Conventional river-based pumped hydro

Tumut 3, Australia

- Head: 151 m
- Water volume: 6 Gigalitres
- Combined reservoir area: 19 km²
- 1.5 GW power rating

Off-river pumped hydro

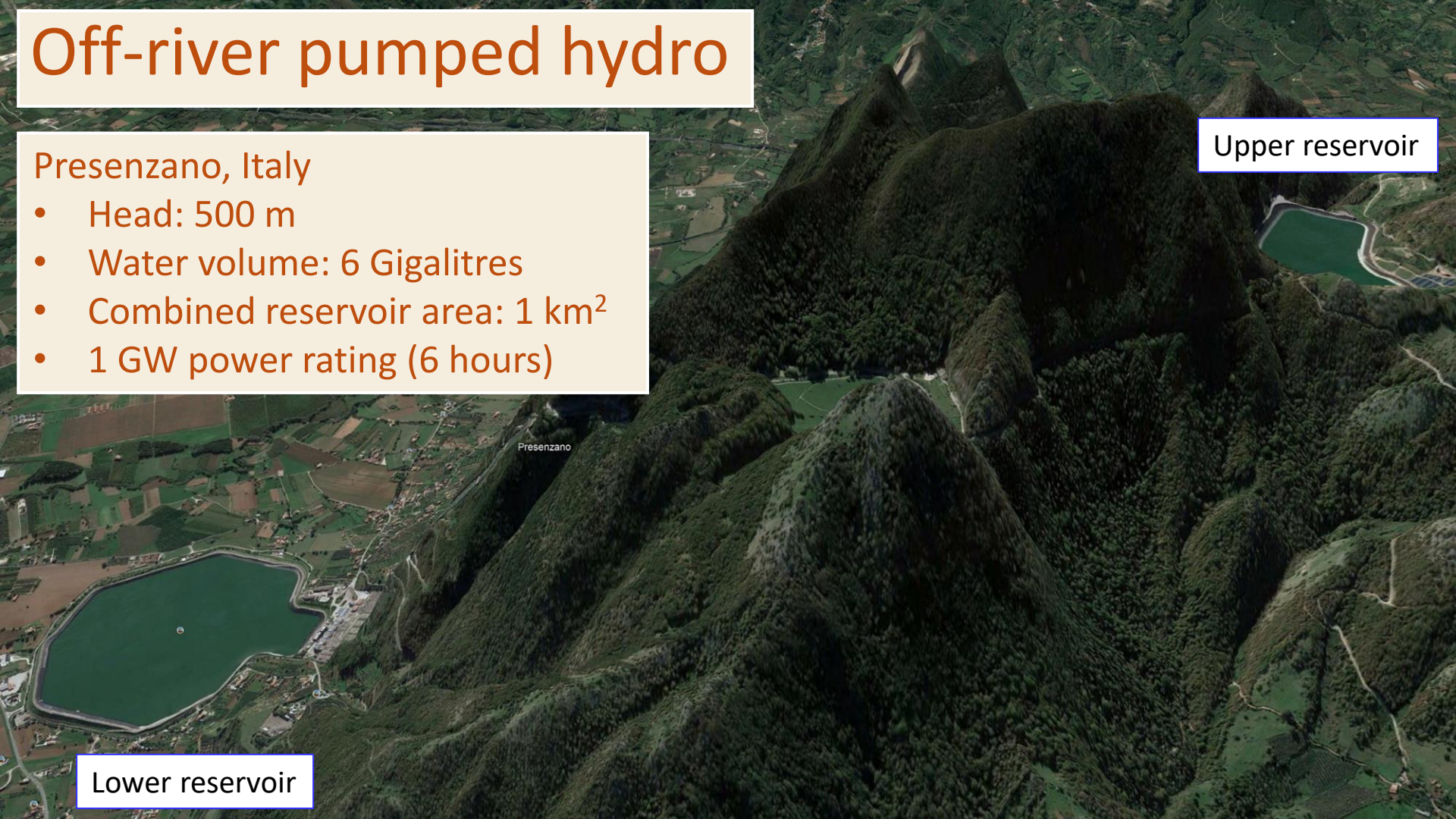
Presenzano, Italy

- Head: 500 m
- Water volume: 6 Gigalitres
- Combined reservoir area: 1 km²
- 1 GW power rating (6 hours)

Upper reservoir

Presenzano

Lower reservoir



Off-river vs on-river pumped hydro

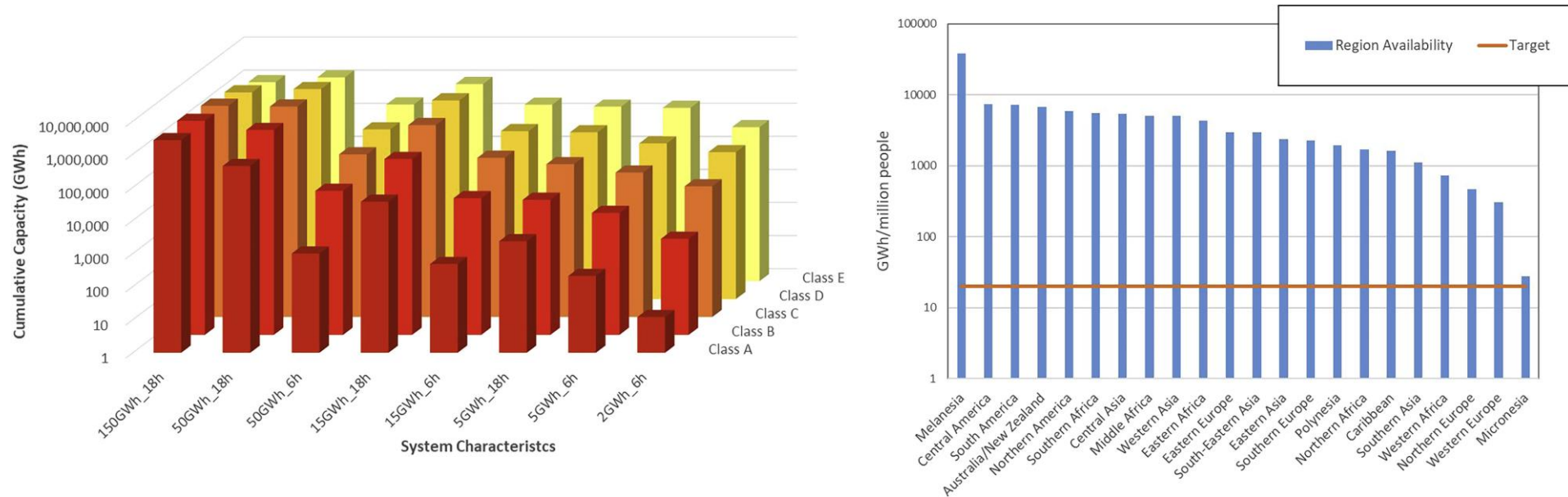
- ✓ ~100 times more sites – be very choosy
- ✓ Fast construction (2-4 years)
- ✓ Low environmental and social pushback
- ✓ Lower costs
 - ❑ Larger head
 - ❑ Minimal flood control



Global atlas of off-river pumped hydro



Distribution of pumped hydro resource



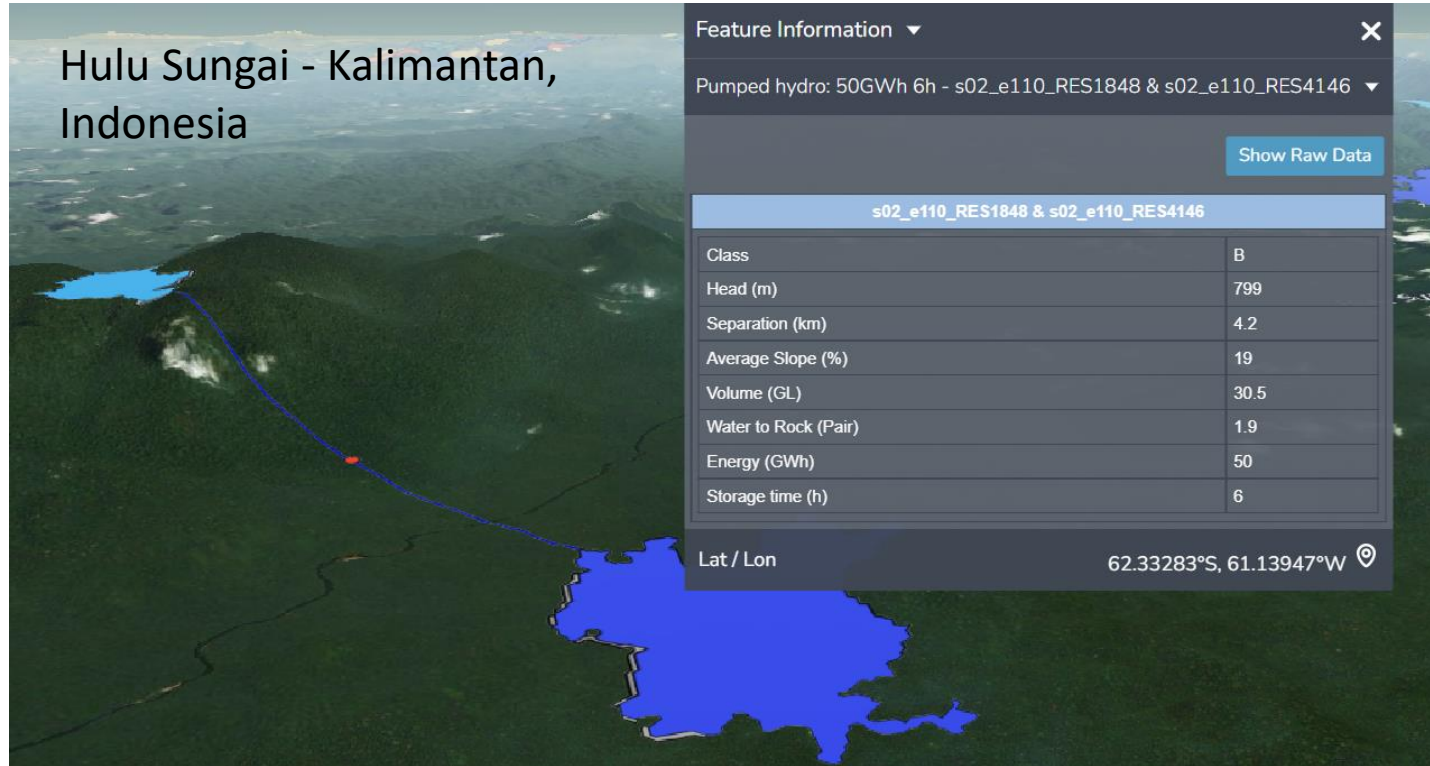
- Required storage to support 100% renewable electricity: 20 GWh per million people
- Every UN sub-region, except for Micronesia, Northern and Western Europe, and Western Africa has more than 1,000 GWh of storage capacity per million people

Pumped hydro sites in Southeast Asia

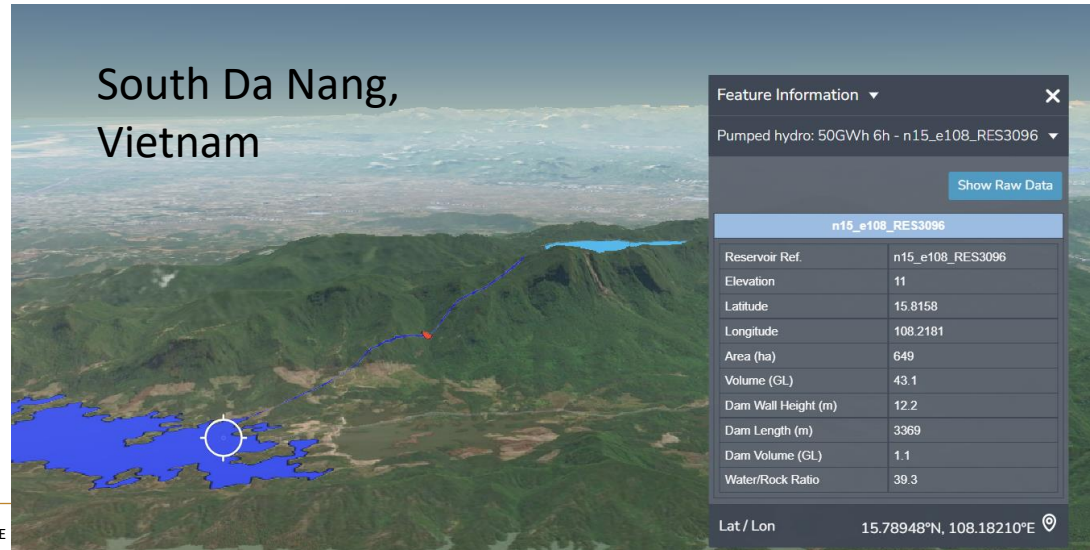
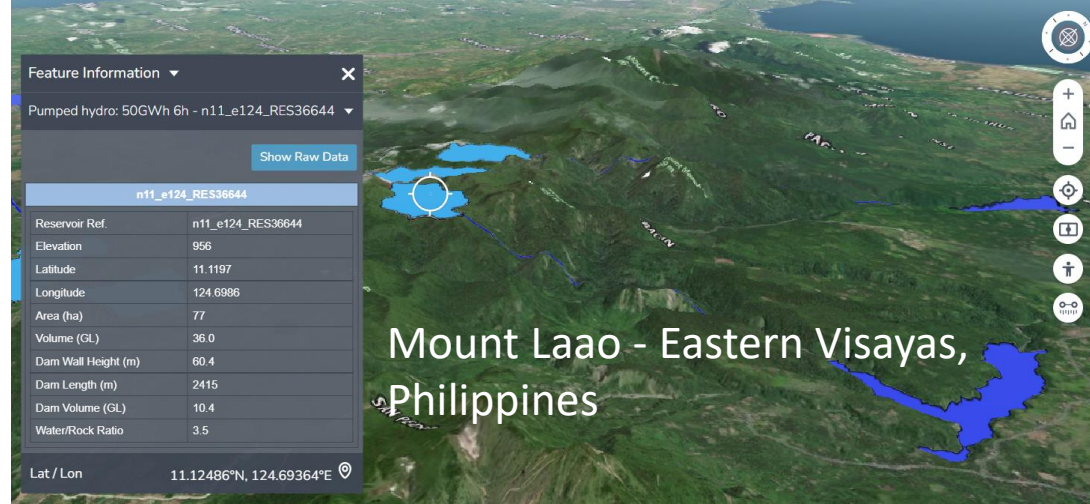


Country	Sites	Capacity (GWh)	GWh per million people	"A" class sites
Indonesia	26,025	821,351	3,047	133,130
Philippines	5,311	160,911	1,488	21,790
Vietnam	6,233	202,518	2,079	61,680

3D Visualization of identified sites

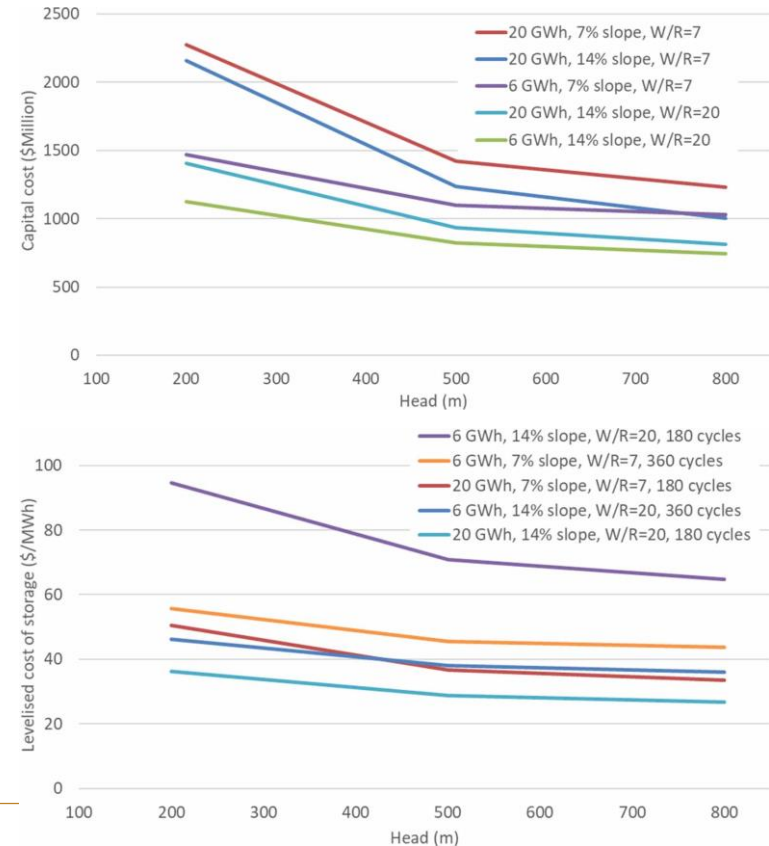


3D Visualization of identified sites



Cost of off-river pumped hydro

- Energy cost (\$/GWh) + power cost (\$/GW)
- Energy cost: mostly of the cost of reservoir construction. Can be minimized by large head and large water to rock ratio.
- Power cost: the cost of the water conveyance and the powerhouse. Can be minimized by large head and large slope of the pipe/tunnel.
- Larger systems are usually cheaper on a per unit basis.



Environmental impacts

- **Land requirement:** 3 m^2 per person
- Land requirement of solar PV to supply 10 MWh per capita per year: 60 m^2 per person
- **Water requirement:** 3 litres per person per day for initial fill (~ 20s of a typical daily shower). Occasional top-ups may be required by evaporation and rainfall are balanced in many places



Pumped hydro projects in Southeast Asia

Indonesia moves forward with 1 GW pumped storage hydropower plant

The World Bank has agreed to finance part of a project owned by Indonesian state-owned utility, PLN. The facility is planned to enable a larger penetration of renewable energy to provide with power two large demand centers in West Java.

SEPTEMBER 13, 2021 **EMILIANO BELLINI**

P6bn pumped hydro storage project to be built in Philippines

OUT-LAW NEWS | 26 Jan 2021 | 12:35 am |



Project 

Bac Ai Pumped Storage Hydropower Project, Ninh Thuan Province

POWER HYDRO PUMPED STORAGE

Project Type :

Pumped storage hydroelectric power generation facility

Location :

Bac Ai District, Ninh Thuan Province, Vietnam

Capacity :

1.2GW

Number of Turbines :

Four



Summary of pumped hydro energy storage

- Pumped hydro is the low-cost, mature, large-scale storage solution
- Vast numbers of potential off-river pumped hydro sites in most regions of the world, far exceeding the number required to support 100% variable renewable electricity systems
- Off river PHES is likely to have low environmental impact and low water consumption



Any questions?

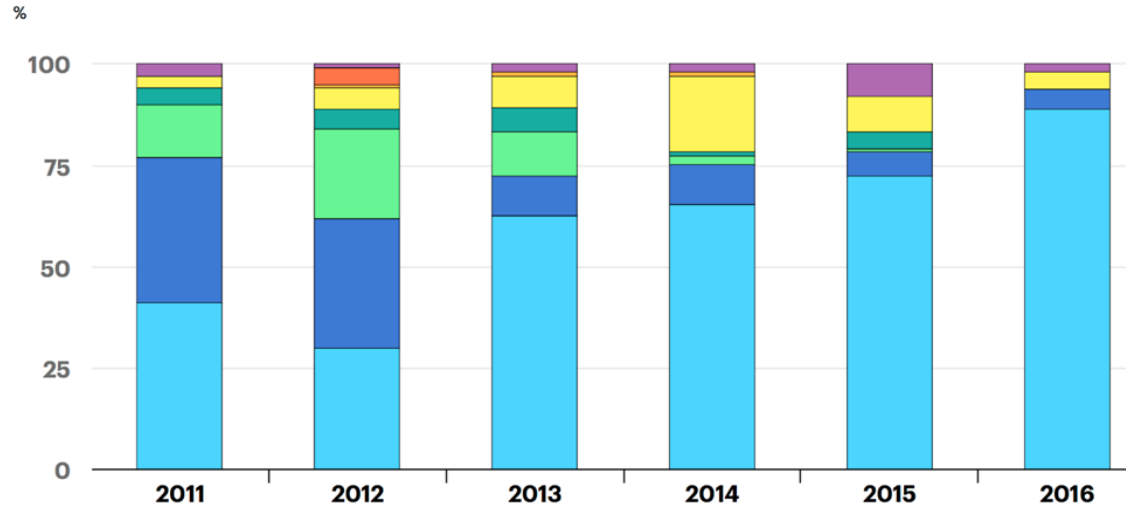


03

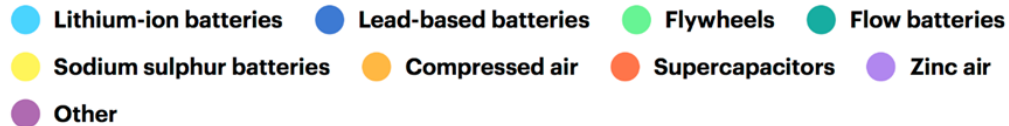
BATTERY STORAGE



Non-pumped hydro grid-scale storage

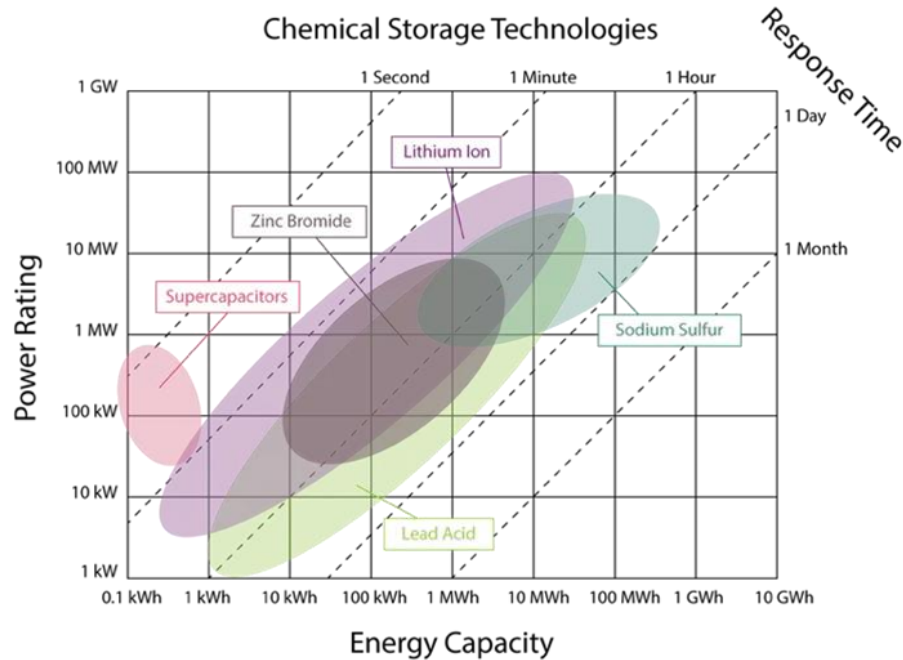


IEA. All Rights Reserved

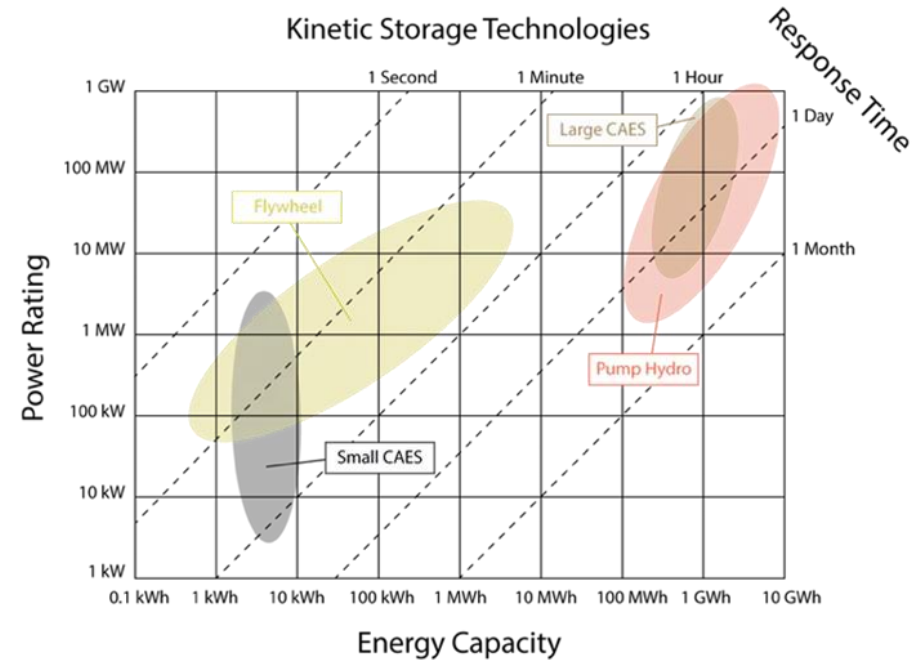


Pumped hydro and batteries are highly complementary

Chemical Storage Technologies

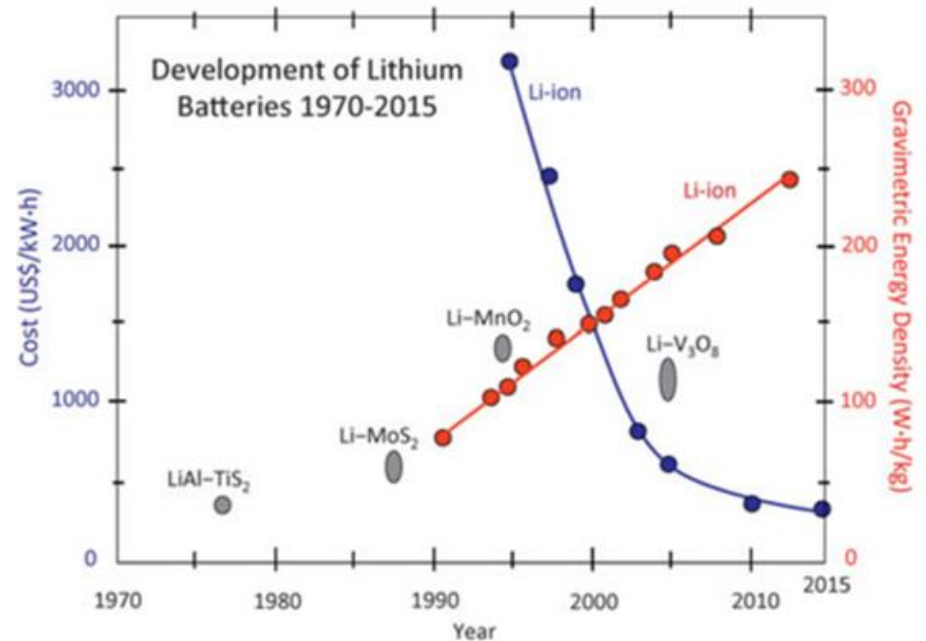


Kinetic Storage Technologies



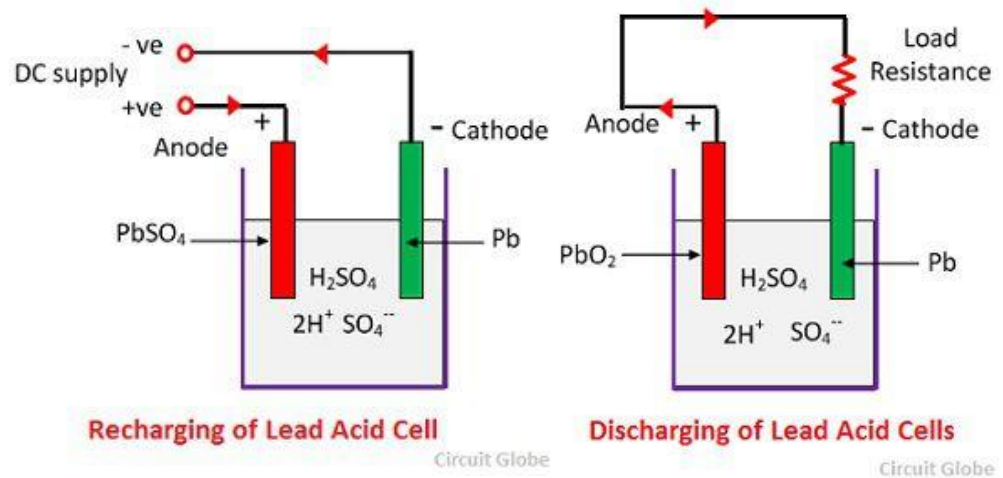
The Emergence of Battery Storage

- High power and fast power response
- Compact
- Modularity
- Geographical distribution
- Getting affordable



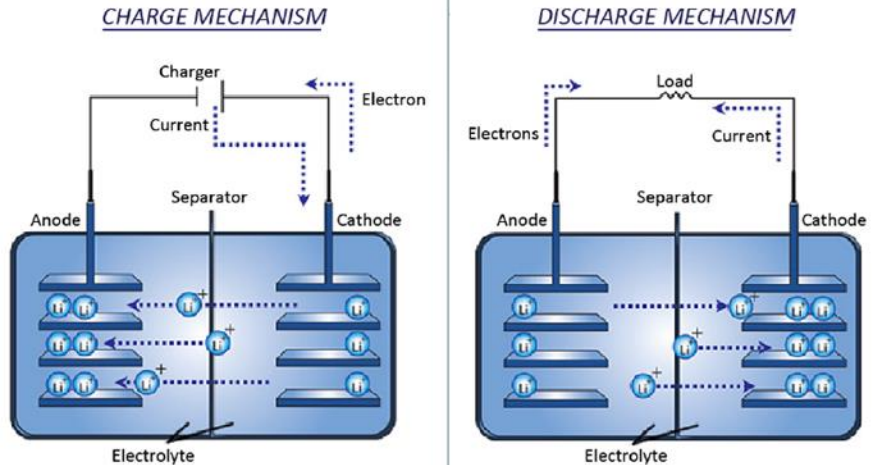
Lead-Acid

- Charge (H^+) transport via liquid or gel (sulfuric) acid electrolyte
- Energy stored via lead electrodes (and also electrolyte)
- Well-established
- Low-energy density
- Shallow depth-of-discharge
- 'Advanced' lead-acid offers better DoD and higher charging rates
- But, low prospects for power system applications



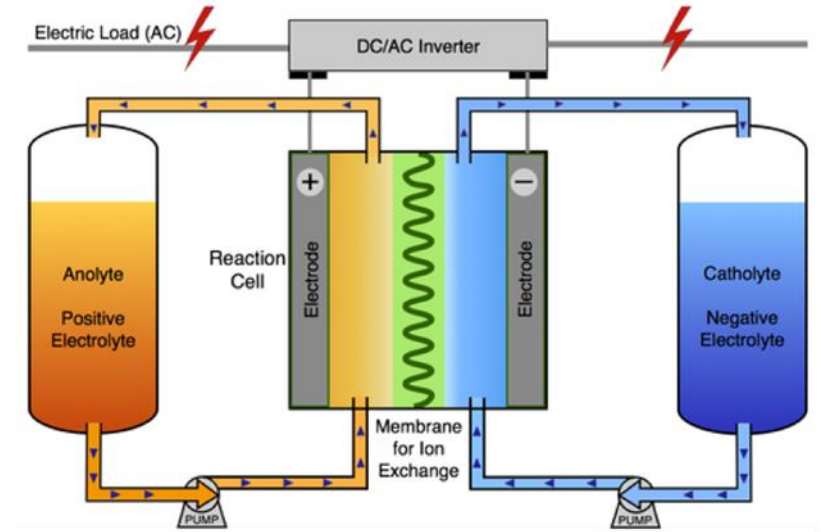
Lithium-ion (various lithium chemistries)

- Currently the dominant technology (mobile and stationary energy)
- Energy stored in electrodes via interactions of Li^+ ions (eg. In graphite)
- Non-aqueous electrolyte (ex: LiPF_6) facilitate charge (Li^+) transport between electrodes
- Many electrode chemistries -> determines properties (E, P, density, cycles, safety)
- High power to energy ratio possible; high energy density



Flow batteries (Redox batteries)

- Commercially less mature, high research attention
- Energy stored in electrolyte; pumped to/from tanks/electrodes
- Various electrolyte chemistries (eg: Vanadium solution); low reaction rate
- High energy to power ratio; low energy density
- Suited for medium-term storage applications

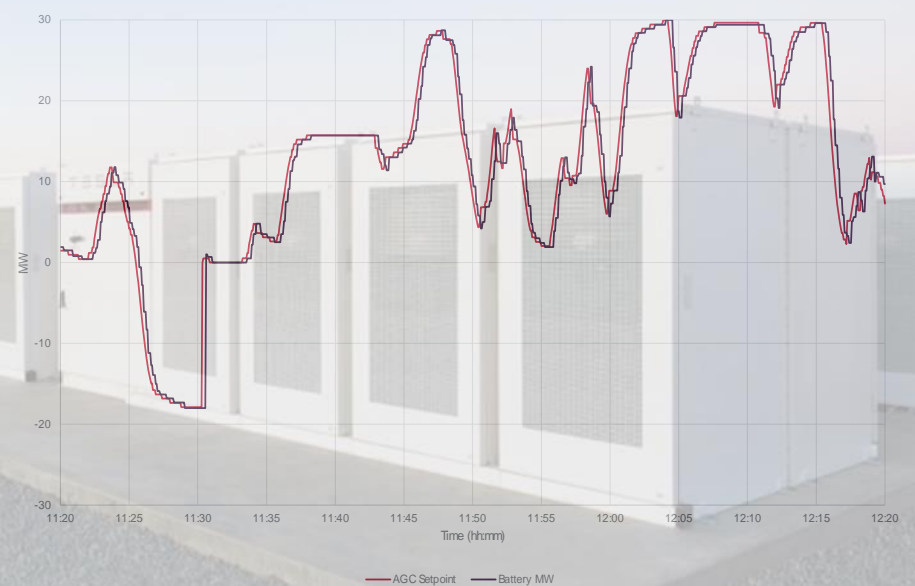


Batteries providing ancillary services

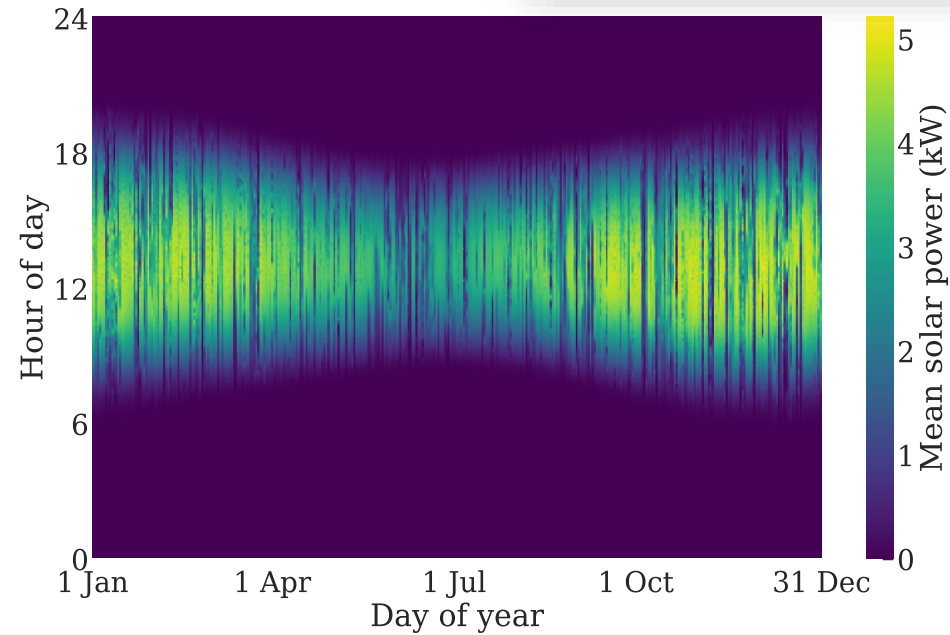
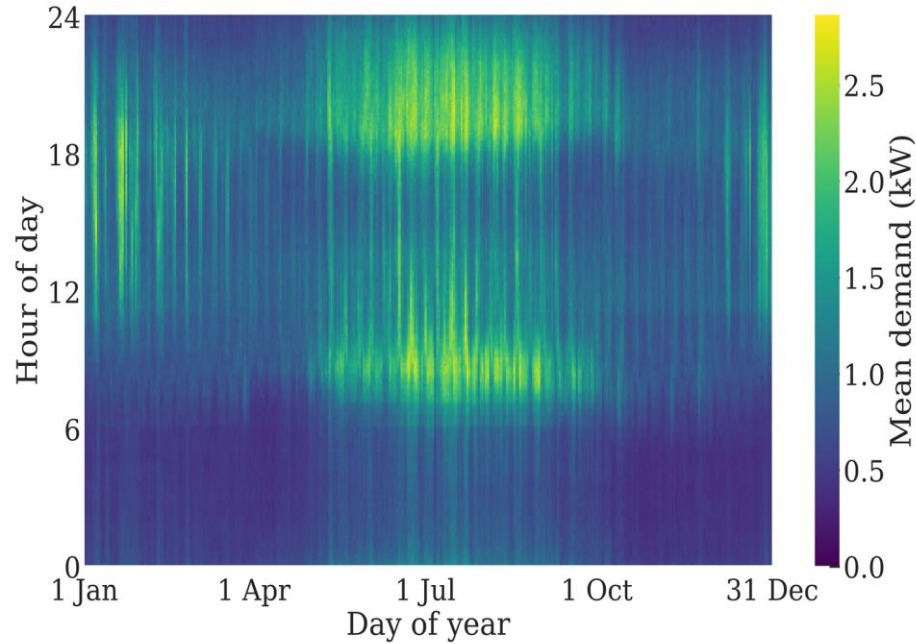
Figure 1 Accuracy and speed of regulation FCAS response – large conventional steam turbine



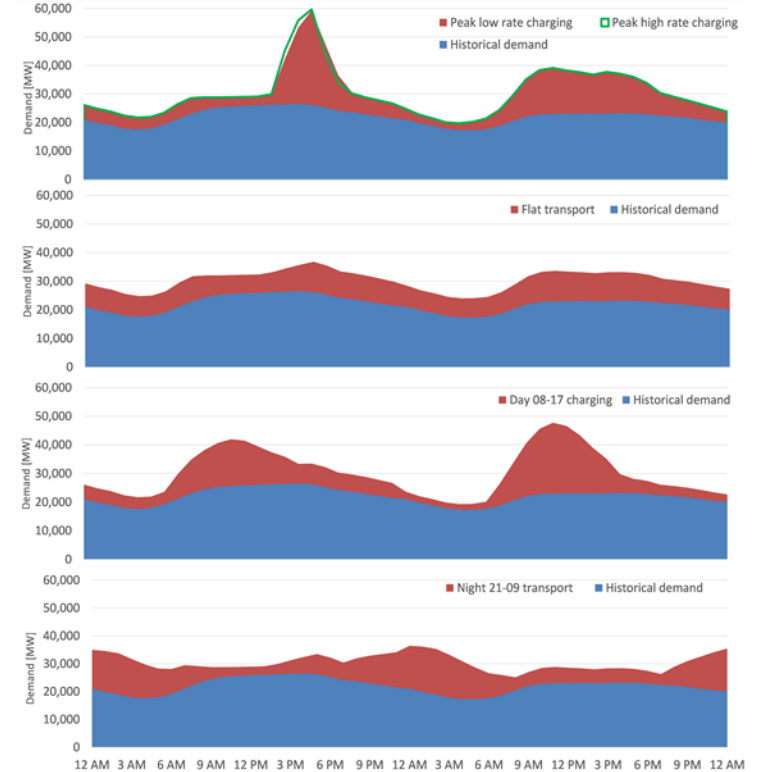
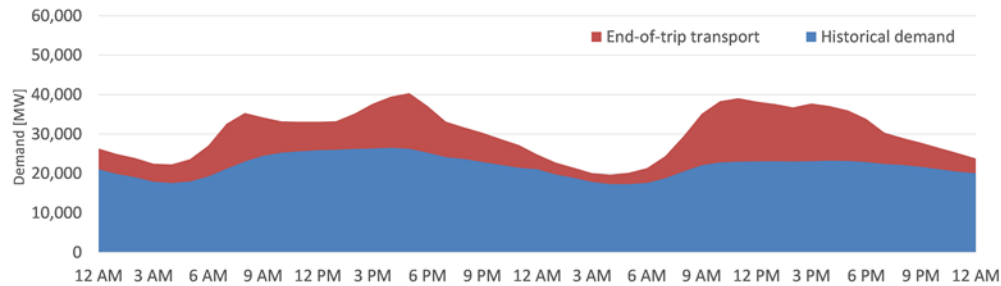
Figure 2 Accuracy and speed of regulation FCAS response – Hornsdale Power Reserve



Demand side analysis



Batteries in electric vehicles



Integrating battery storage into the grid

- How do we best use battery storage and power electronics to provide voltage and frequency stability?
- How best can battery storage and power electronics provide inertia and system strength?
- How do you share a synchronisation signal (i.e. timing consensus) across millions of distributed devices?

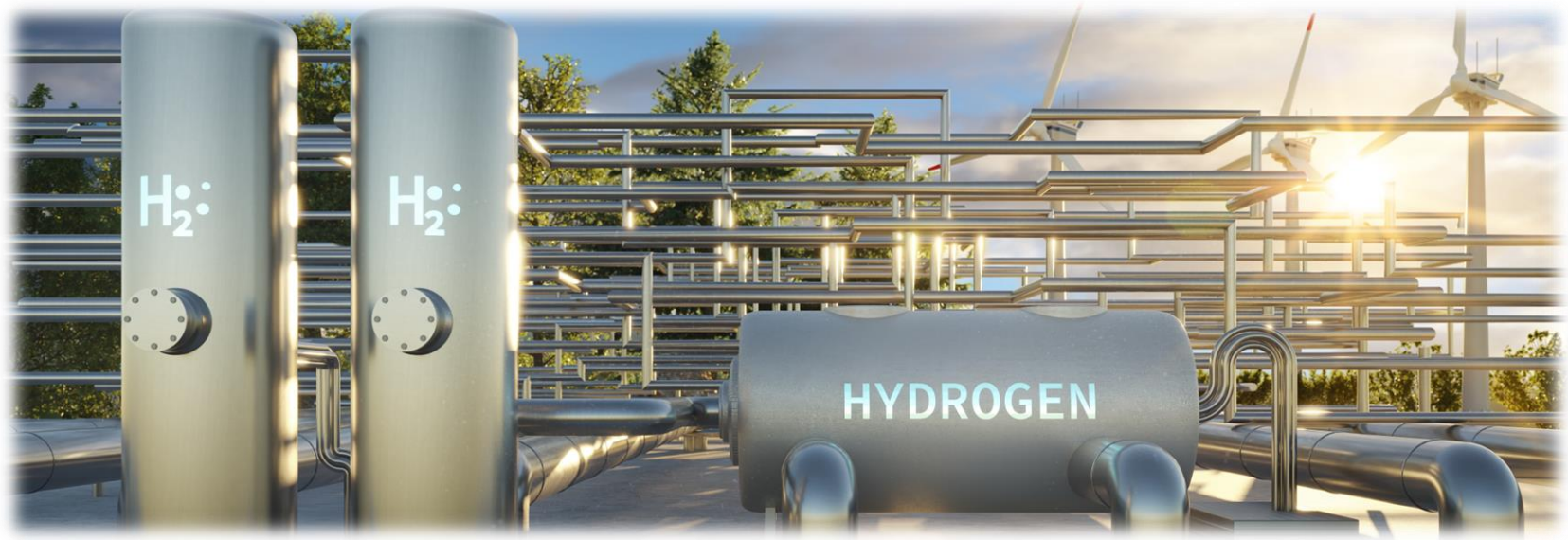


Any questions?

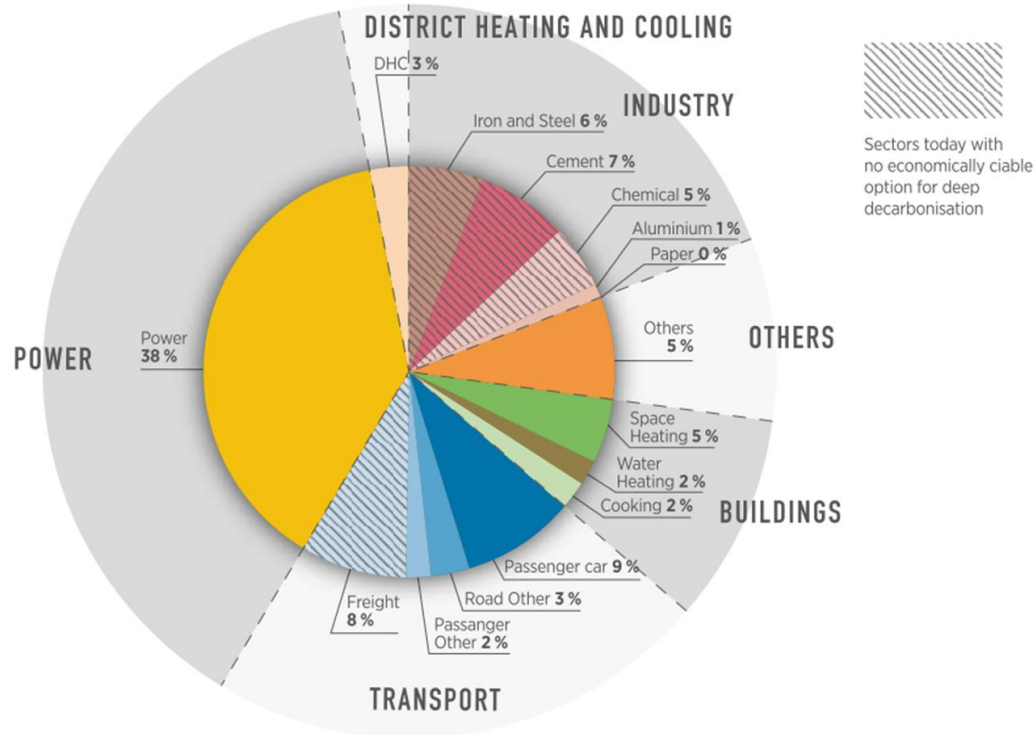


04

HYDROGEN



Sectors that are difficult to be directly electrified



Properties of hydrogen

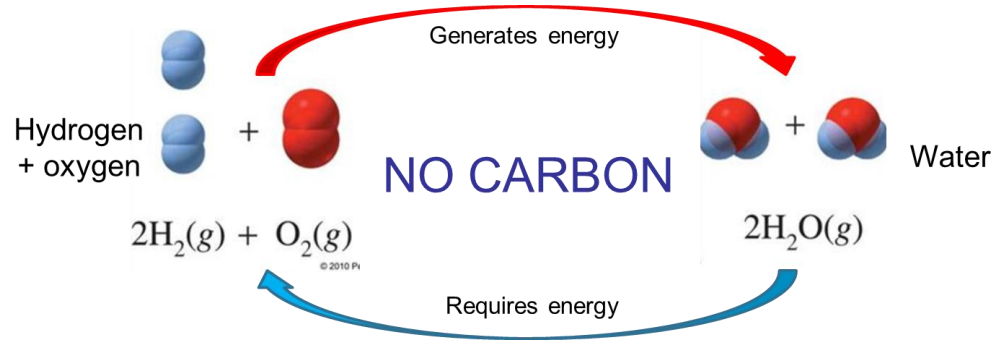
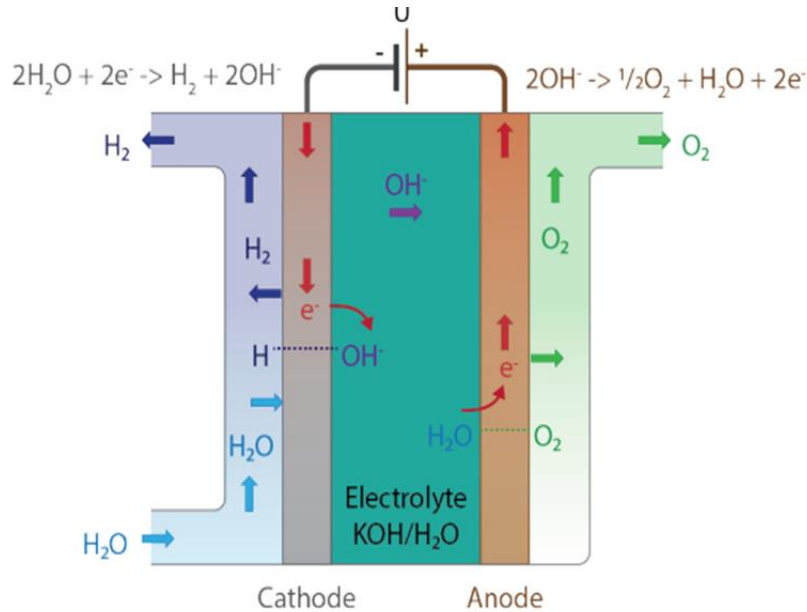


Table 2. Physical properties of hydrogen

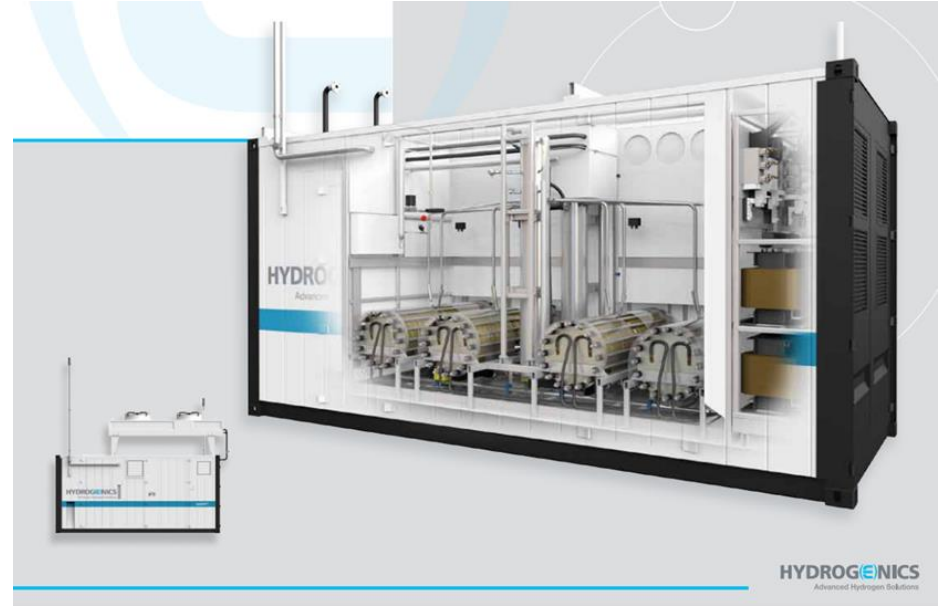
Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m ³ (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.79 kg/m ³ (-253°C, 1 bar)	1/6 of natural gas
Boiling point	-252.76°C (1 bar)	90°C below LNG
Energy per unit of mass (LHV)	120.1 MJ/kg	3x that of gasoline
Energy density (ambient cond., LHV)	0.01 MJ/L	1/3 of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/L	1/3 of LNG



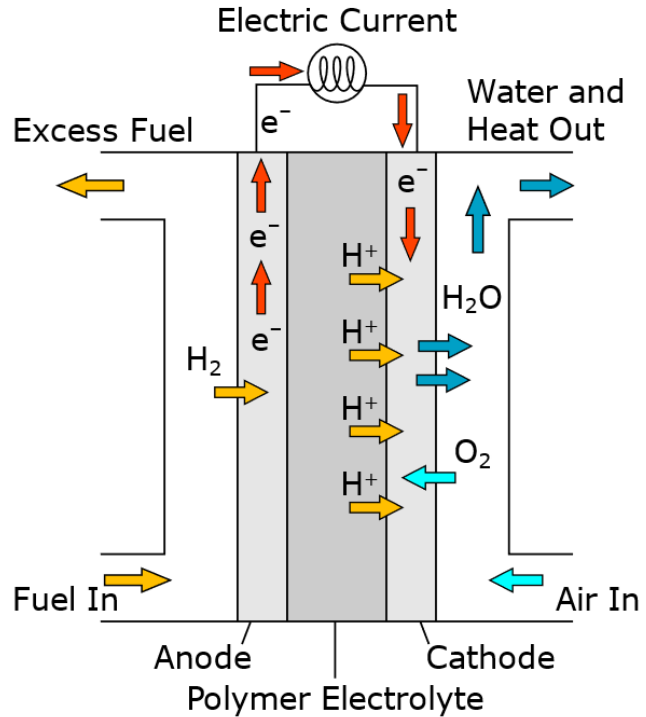
Hydrogen production - electrolyzers



(b)

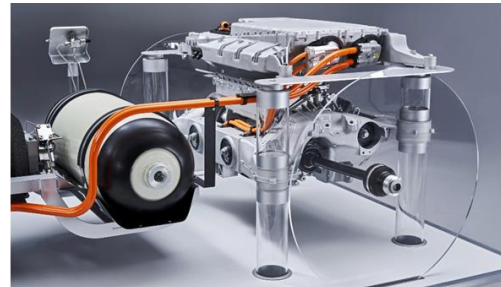


Hydrogen combustion – fuel cell



SureSource 1500™ – 1.4 Megawatts

<https://www.fuelcellenergy.com/>

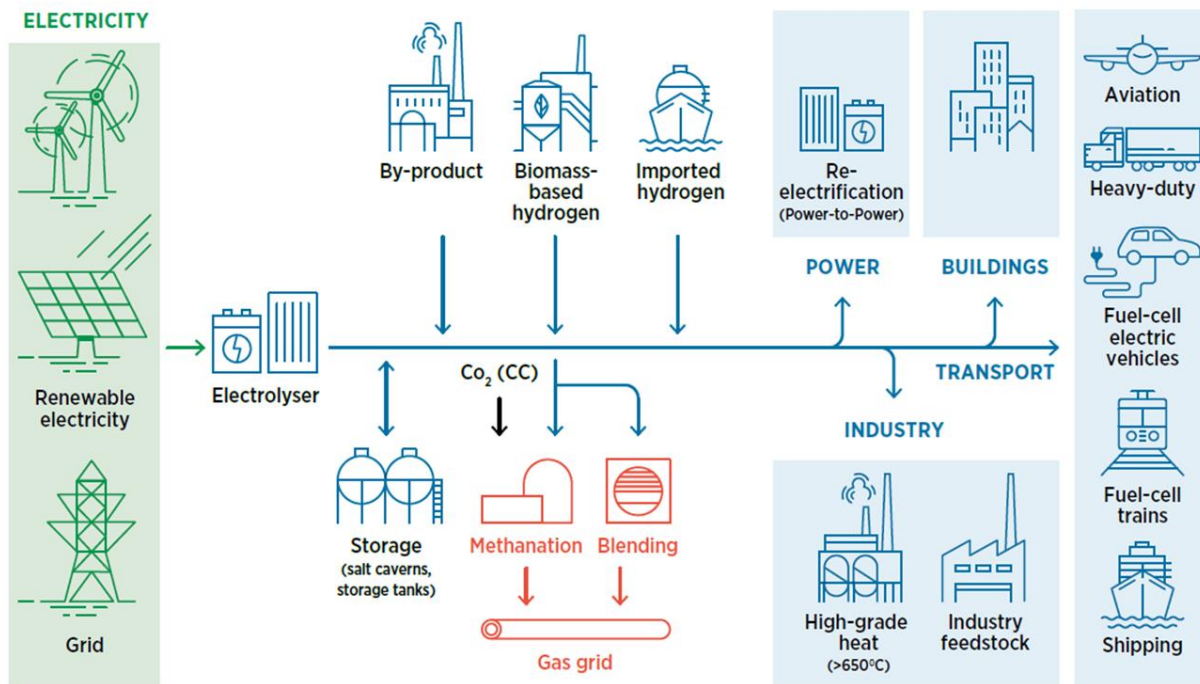


BMW group <https://totallyev.net/bmw-reaffirms-its-commitment-to-hydrogen-fuel-cell-technology/>

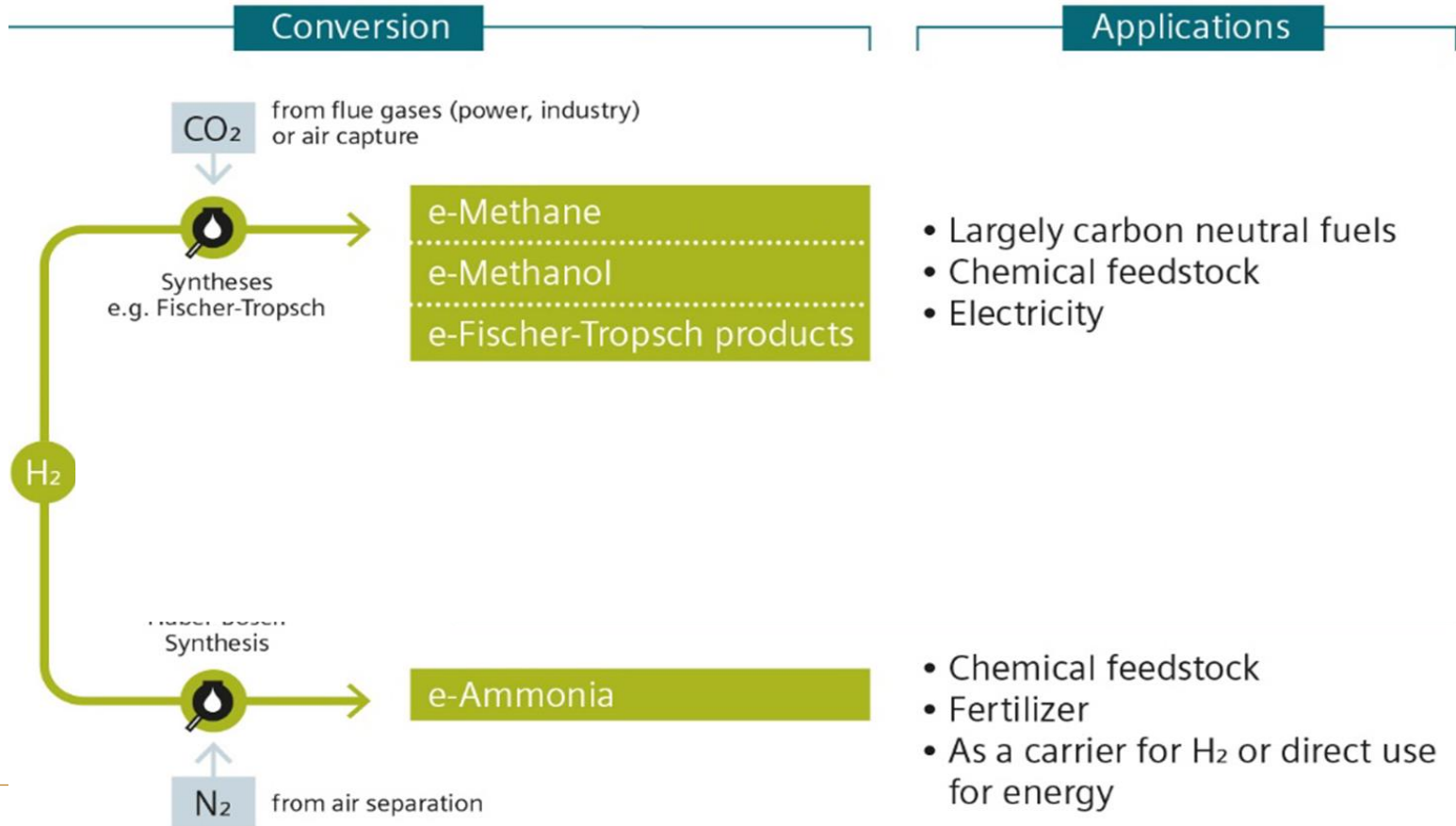


Power to X options

Figure: Integration of VRE into end-uses by means of hydrogen

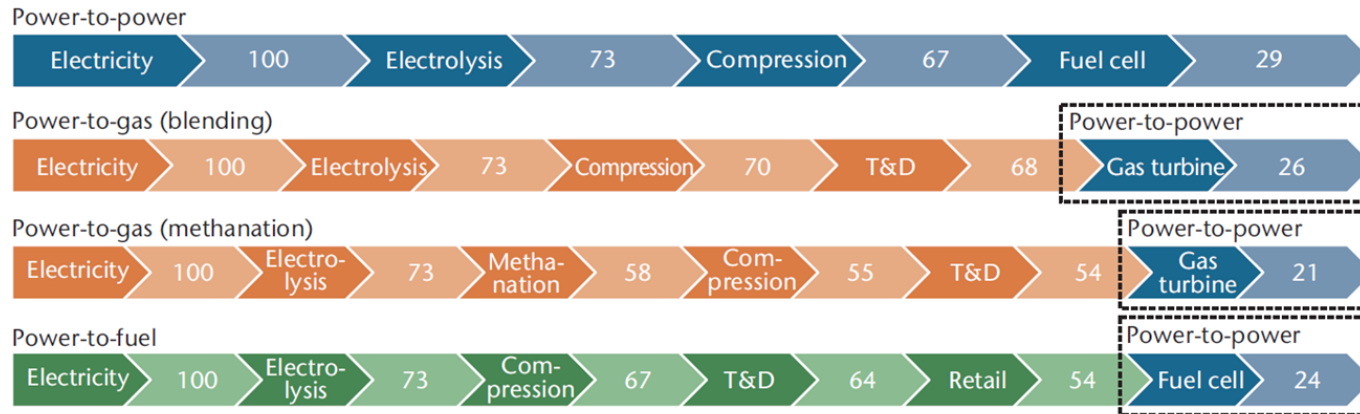


Hydrogen derivatives and e-fuels



Hydrogen as energy storage

Figure 6: Current conversion efficiencies of various hydrogen-based VRE integration pathways



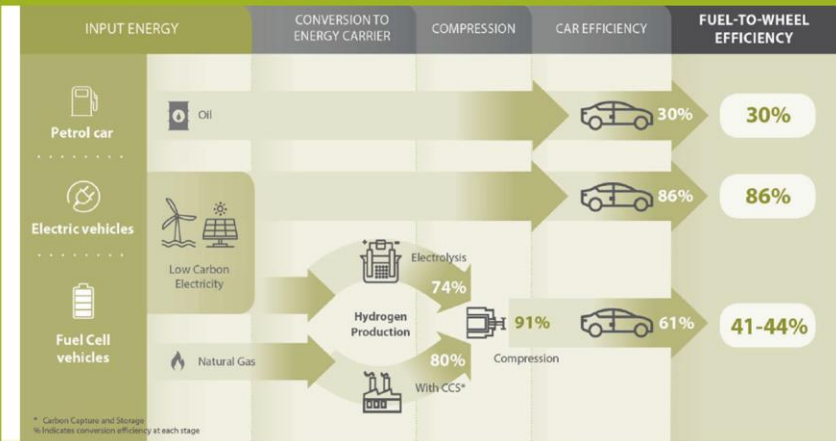
Note: The numbers denote useful energy; except for gas turbines, efficiencies are based on HHV; the conversion efficiency of gas turbines is based on LHV.

KEY POINT: Total round-trip efficiencies of hydrogen-based energy storage applications are low.



Hydrogen efficiencies

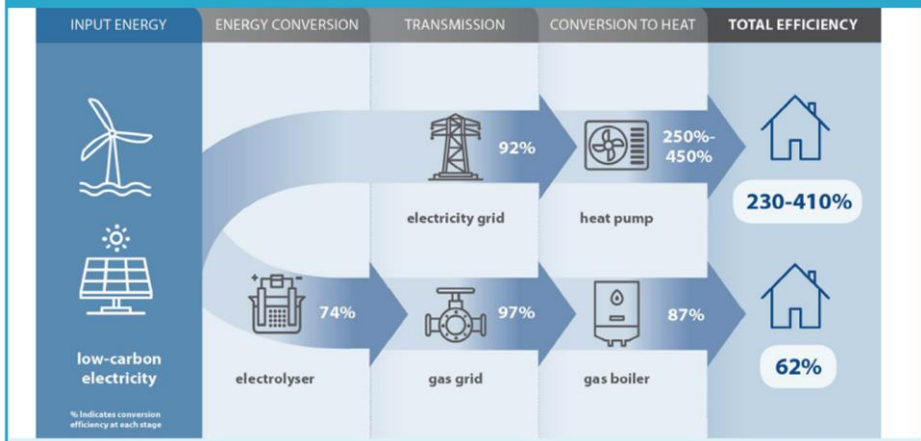
Figure 2.2. Relative efficiency of battery electric vehicles vs. electrolytic hydrogen fuel cell vehicles



Source: CCC analysis.

Notes: The diagram shows the indicative efficiency of using a given amount of zero-carbon electricity in powering a car. Whilst in practice each of the efficiency numbers could vary, this would not be sufficient to change the conclusion that electric vehicles provide a much more efficient solution for powering vehicles than use of electrolytic hydrogen in a hydrogen fuel cell vehicle.

Figure 1.2. Relative efficiency of heating: electricity in heat pumps vs. electrolytic hydrogen in boilers



Source: CCC analysis.

Notes: The diagram shows the indicative efficiency of using a given amount of zero-carbon electricity in delivering heat for buildings. Whilst in practice each of the efficiency numbers could vary, this would not be sufficient to change the conclusion that heat pumps provide a much more efficient solution for providing heat from zero-carbon electricity than use of electrolytic hydrogen in a boiler.



Hydrogen: The Swiss Army Knife

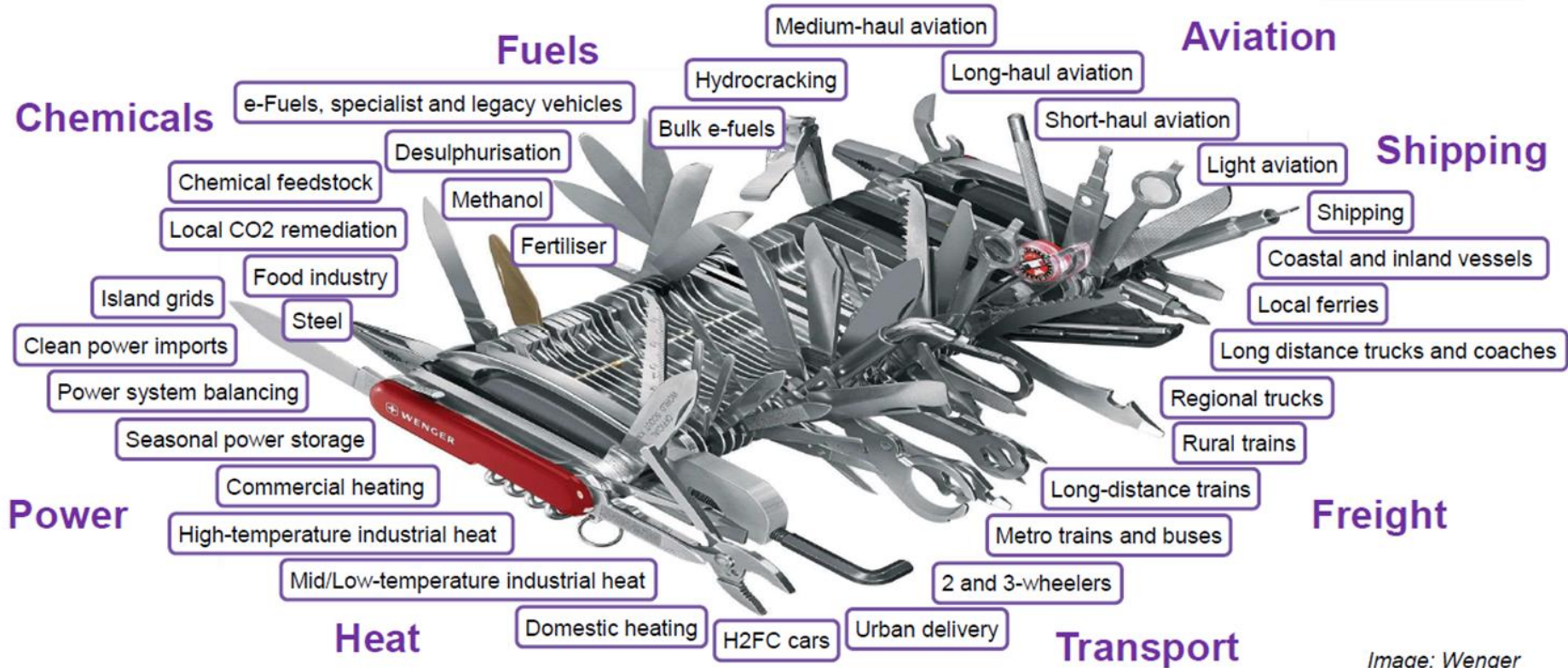


Image: Wenger

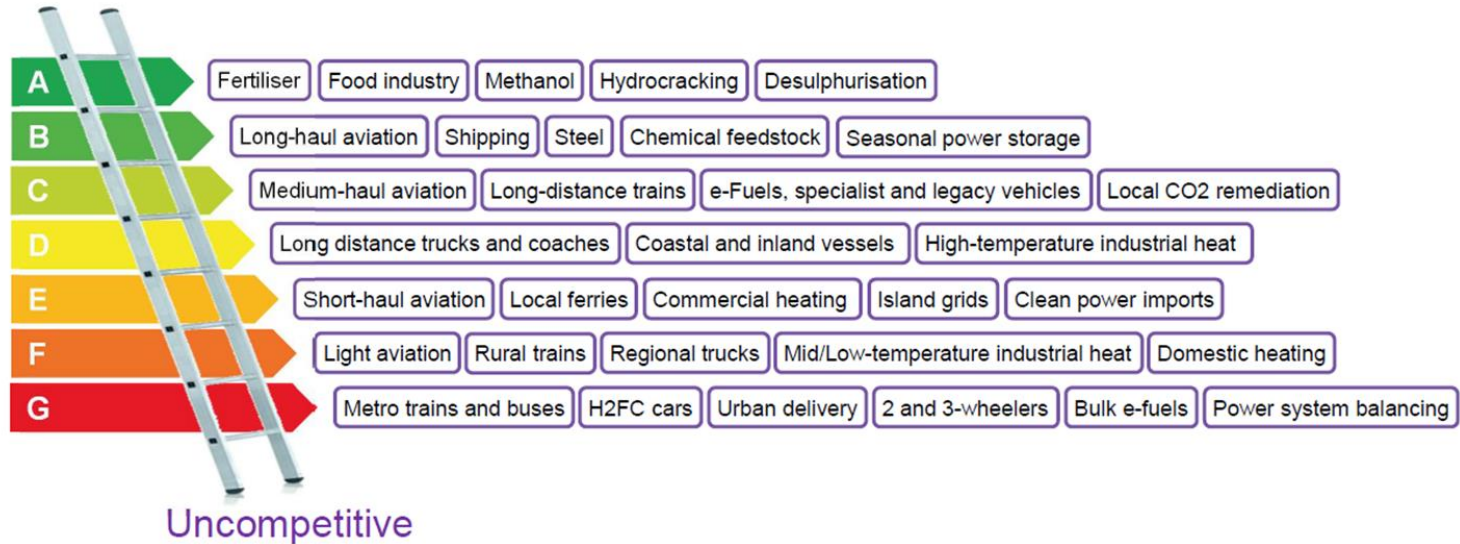


Ranking hydrogen applications

Liebreich
Associates

Hydrogen: The Ladder

Unavoidable



Source: Liebreich Associates Concept: Adrian Hiel/Energy Cities

1 25 May 2021



Any questions?



Reading materials

- A review of pumped hydro energy storage (provided)
- Global Atlas of Closed-Loop Pumped Hydro Energy Storage (provided)
- Global Pumped Hydro Atlas: <http://re100.eng.anu.edu.au/global/index.php>
- Proof of Energy Storage Chapter, "Transitioning to a Prosperous, Resilient and Carbon-Free Economy" (provided)
- Proof of Hydrogen Economy Chapter, "Transitioning to a Prosperous, Resilient and Carbon-Free Economy" (provided)

