CLEAN ENERGY INSTITUTE

UNIVERSITY *of* WASHINGTON

Grid Energy Storage

Accelerating the creation of a scalable, clean energy future

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Energy (Density) & Power (Density)

- Energy □ the ability to do work [J, kWh]
- Power □ how fast energy is used or produced [J/s = W]
- Density □ energy (power) stored per weight (volume) [Wh/kg]

Tesla Model S

Chevrolet Bolt

	Tesla Model S	Chevrolet Bolt
• Range:	390 miles	259 miles
• 0-60 mile:	1.99 s	6.5 s
• Battery:	Panasonic (246 Wh/kg)	LG (237 Wh/kg)

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Power Scales

1 Watt

laptop computer

15-30 watts

human body base metabolism

80 watts

1 kW (10^3 W)

microwave

1 kilowatt

small solar panel array
(peak production)

1.5 kilowatt

1 MW (10^6 W)

flying a Boeing 747

140 megawatts

wind turbine
(2011 GE 2.5 MW)

2.5 megawatts

1 GW (10^9 W)

average power use of Washington (2010)

68 gigawatts

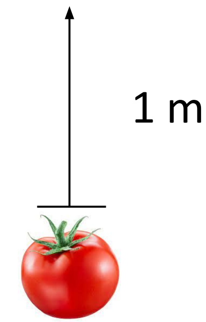
average power use of United States (1940)

840 gigawatts

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Energy Scales

1 J



1 Wh = 3600 J

Panasonic 18650 B Li battery
9.13 Wh

1 kWh (10^3 Wh)

Tesla Powerwall
13.5 kWh

Average US household
daily energy consumption
28.9 kWh

1 MWh (10^6 Wh)

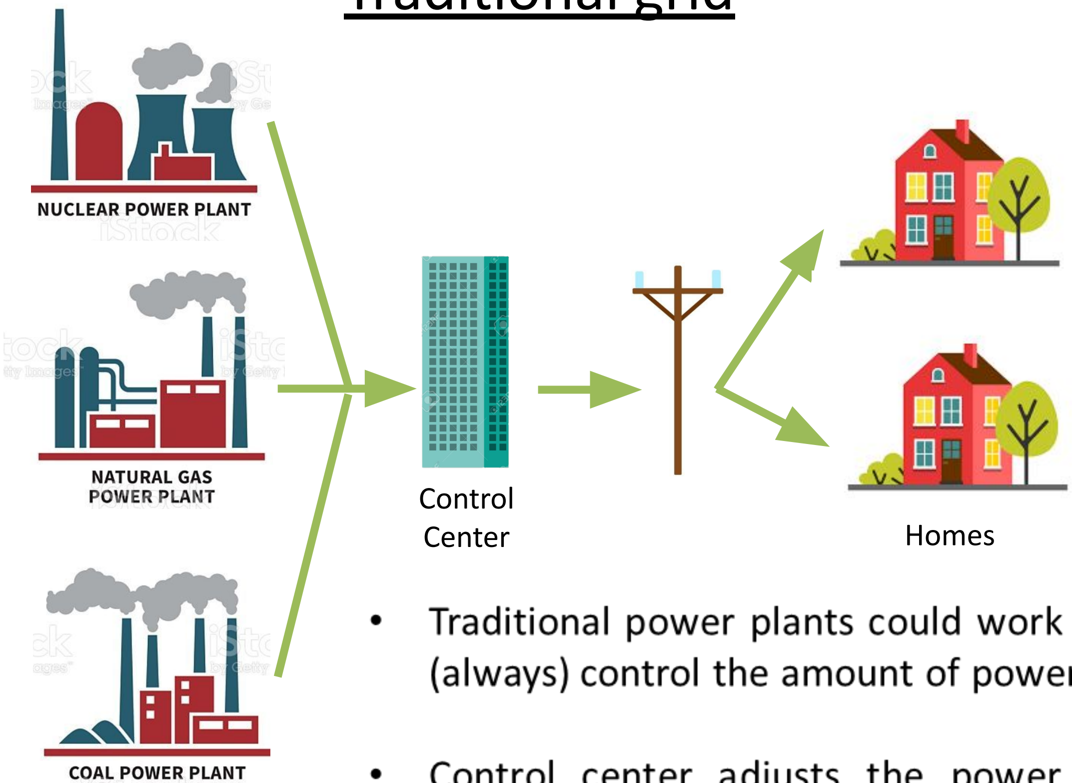
1 GWh (10^9 Wh)

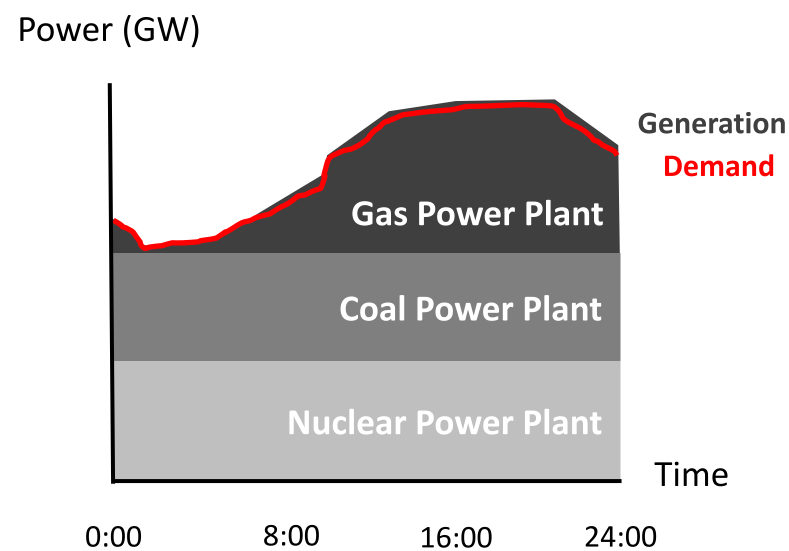
average <u>daily</u> energy consumption
of United States (2020)
10,416 GWh

Why grid energy storage matters for 100 % clean energy?

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Traditional grid



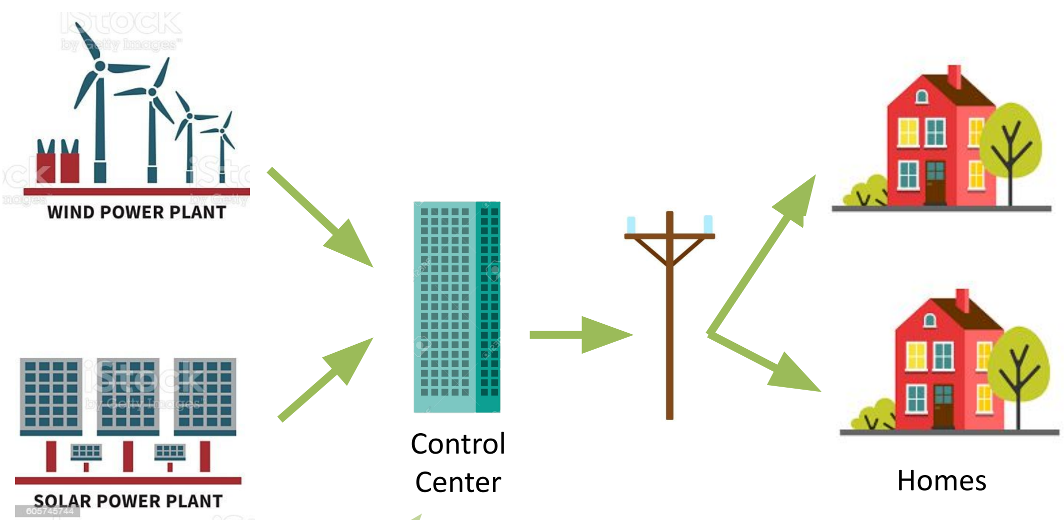


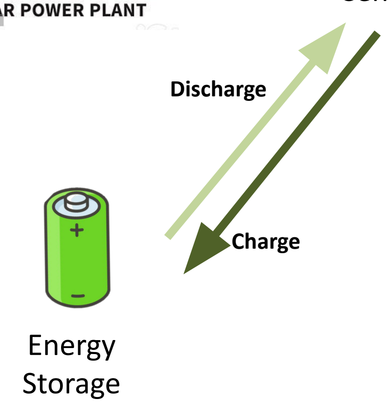
- Traditional power plants could work 24 hours a day, 365 days a year, and we could (always) control the amount of power generated at any given time
- Control center adjusts the power generated over time to ensure the power Generation ≅ Demand. The imbalance of generation and demand will cause the power grid to crash
- For traditional grid, we use most of the energy generated right away, and the energy storage demand is relatively low

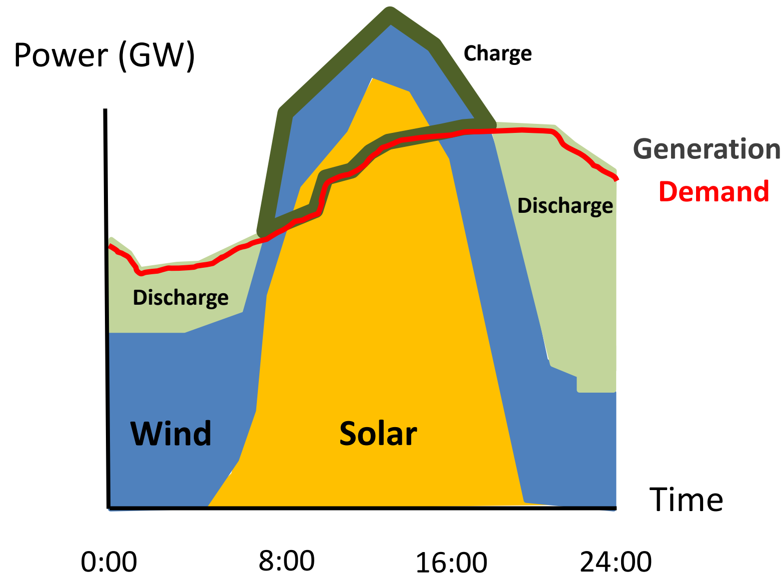
CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Why grid energy storage matters for 100 % clean energy?

Smart grid (simplified)







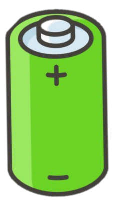
- We can't control the amount of power generated from wind or solar. We install 2.5 MW wind turbine capacity and expect the maximum power output to be 2.5 MW, but it could be 0 MW at some time point.

- We could predict the amount of energy that will be generated by solar or wind (challenging), and either store the extra or fill up the shortage using energy storage system

- Very high energy storage demand to smooth the energy generation curve

CLEAN ENERGY INSTITUTE
UNIVERSITY *of* WASHINGTON

Grid energy storage considerations



Grid Energy Storage

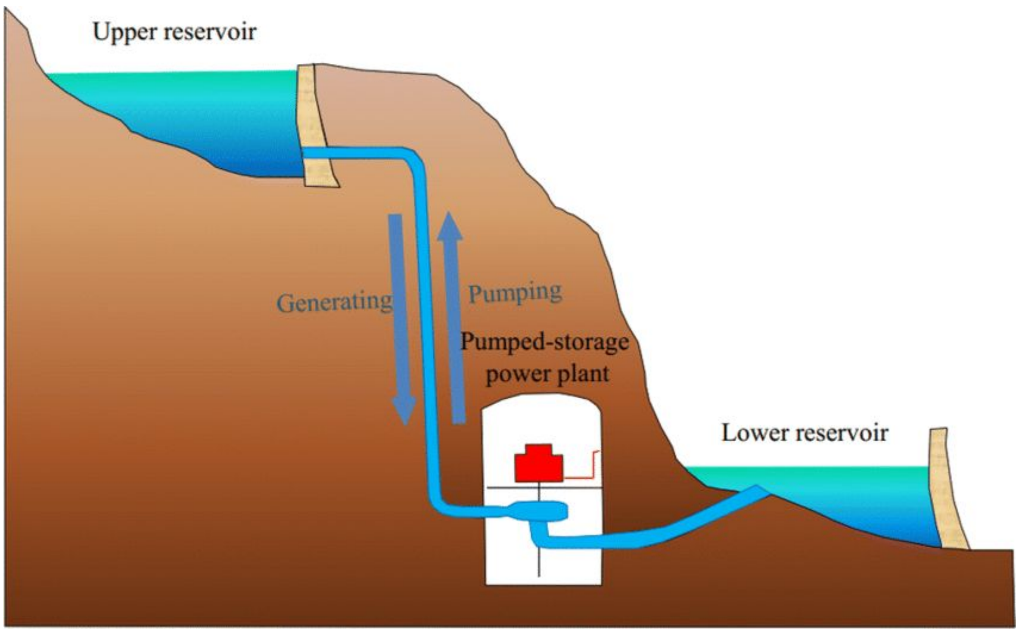
(Levelized) Cost	USD/kWh. The average cost of total energy stored (multiple store-release cycles) over the lifetime of the energy storage facility
Efficiency	$\frac{\text{Energy released (electrical)}}{\text{Energy stored (mechanical, electrochemical, chemical)}}$
Energy density	Watt—hour per litter, how much space is required
Safety	High energy storage = great ability to work normally (discharge) or abnormally (fire or explosion)
Discharge time	1,200 MWh □ 300 MW – 4 hours □ 600 MW – 2 hours
Max cycle or lifetime	Years or > 1,000 cycles, how long to replace the unit

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Different grid energy storage forms

Mechanical

Pumped Hydro



(Levelized) Cost	***Low***
Efficiency	Medium
Energy density	Low
Lifetime	Long

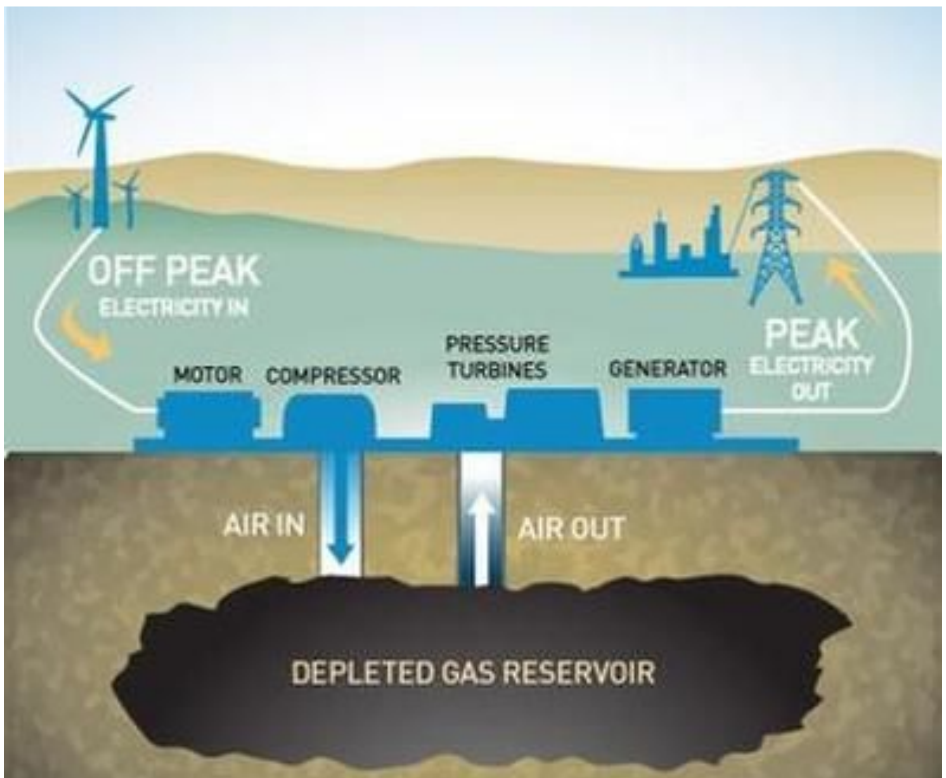
- 95 % energy storage, very mature technology
- Snoqualmie falls, Grand Coulee Dam (WA)
- Location limitation

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Different grid energy storage forms

Mechanical

Compressed Air Energy Storage (CAES)



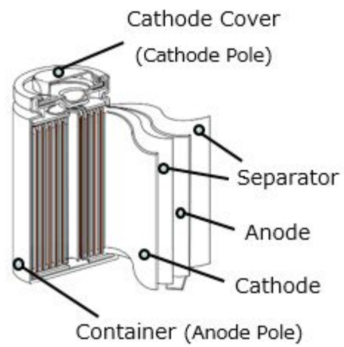
(Levelized) Cost	***Low***
Efficiency	Low-Medium
Energy density	Low
Lifetime	Long

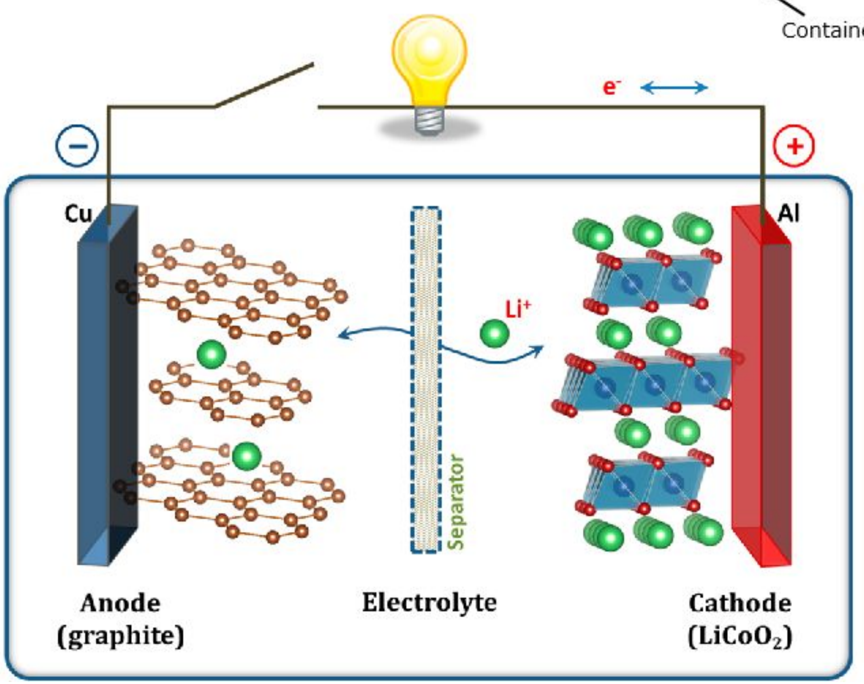
- Eastern Washington is rich with potentially suitable sites for CAES.

Different grid energy storage forms

Electrochemical

Li Ion Battery





$$LiC_6 + CoO_2 \leftrightarrow C_6 + LiCoO_2 + \textbf{Energy}$$

(Levelized) Cost	Medium
Efficiency	***High***
Energy density	High
Lifetime	Medium

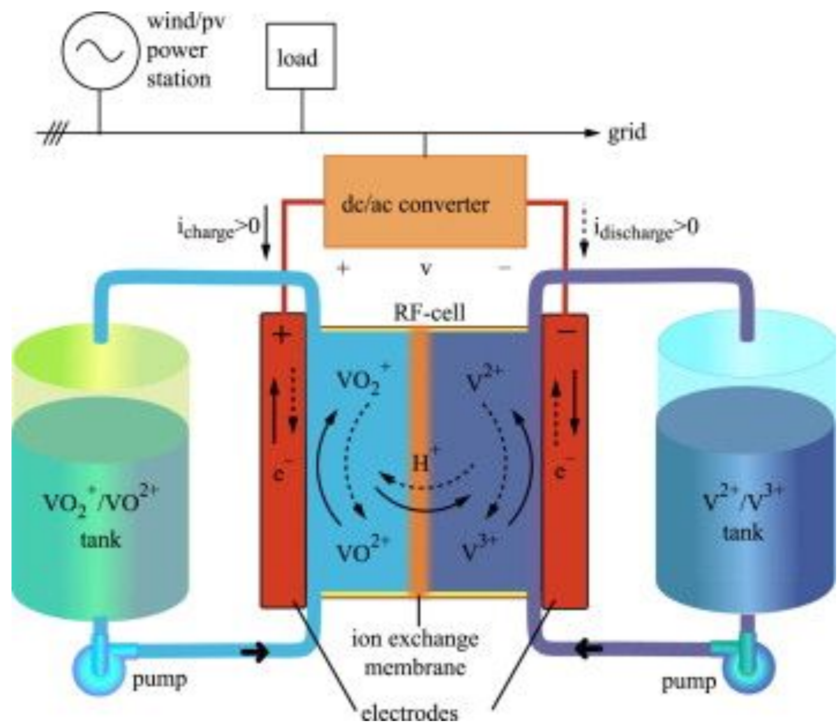
- Potential safety concern

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Different grid energy storage forms

Electrochemical

Vanadium Flow Battery (VFB)



$$VO_2^+ + 2H^+ + V^{2+} \leftrightarrow VO^{2+} + H_2O + V^{3+} + \textbf{Energy}$$

(Levelized) Cost	Medium
Efficiency	Medium
Energy density	Medium
Lifetime	Medium

- *No safety concern, no location limitation.*

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

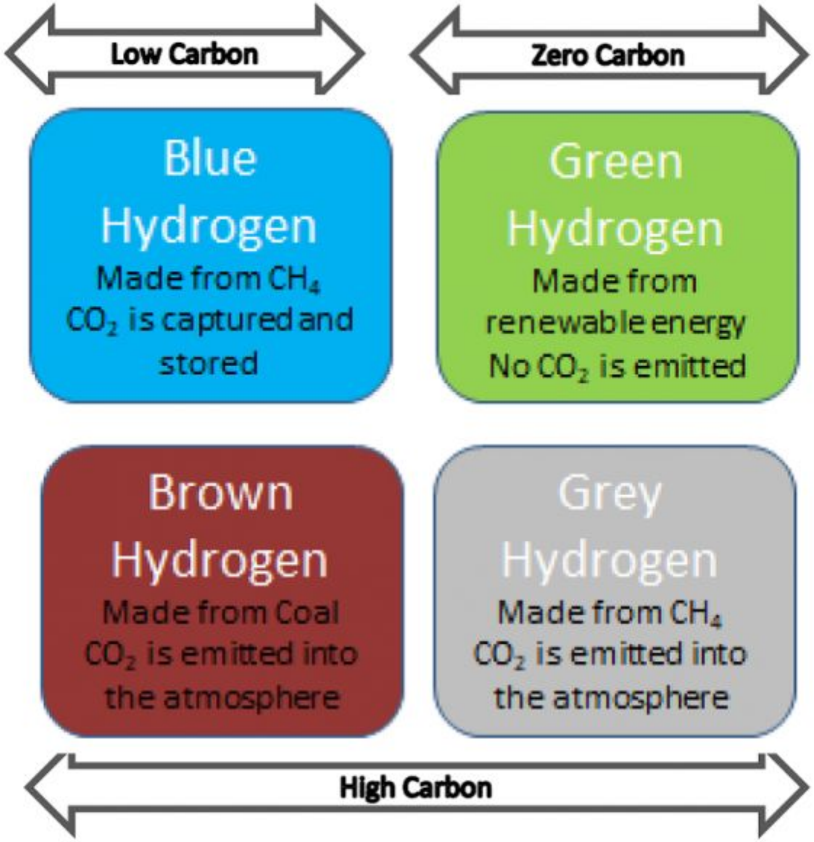
Different grid energy storage forms

Chemical

Hydrogen generation (energy storage)

$CH_4 + 2H_2O$ + **Energy** $\rightarrow$ $CO_2 + 2H_2$

$2H_2O$ + **Energy** $\rightarrow$ $O_2 + 2H_2$

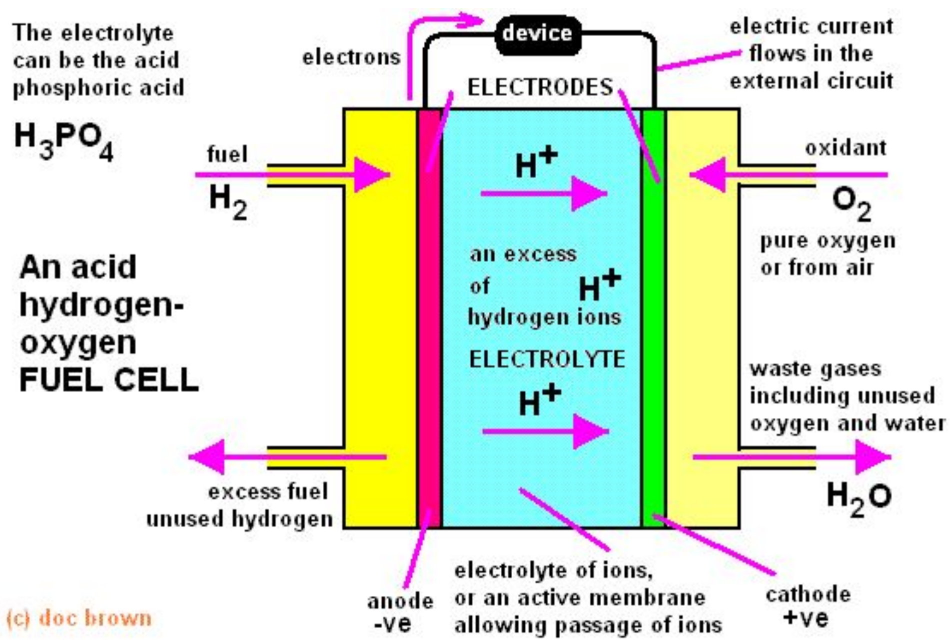


CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Different grid energy storage forms

Chemical

Fuel Cell (energy release)



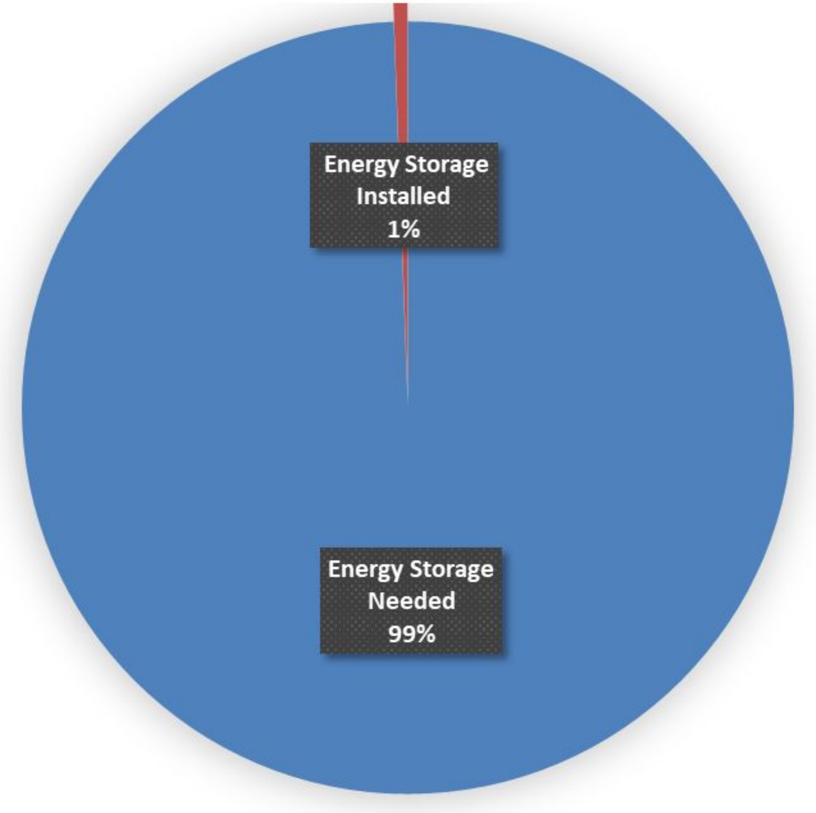
$2H_2 + O_2$ □ H_2O + **Energy**

(Levelized) Cost	High
Efficiency	Low-Medium
Energy density	***High***
Lifetime	Medium-Long

- Potential safety issue
- Storage/transportation is challenging

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Key challenge to 100 % renewable energy



- The power demand in US in 2020 is ~ 500 GW.
- The largest Li battery storage system today is ~ 0.3 GW (4 hours)
- To smooth the energy generation curve, we need energy storage unit at least **150 GW (4 hours) for 90 % renewable energy usage**. The storage capacity in US is ~ 3.5 GWh in 2020.

- **Foreseeable future:**
  - ✔ The combination of different energy storage technologies
  - ✔ Highly region-dependent energy storage strategies

CLEAN ENERGY INSTITUTE

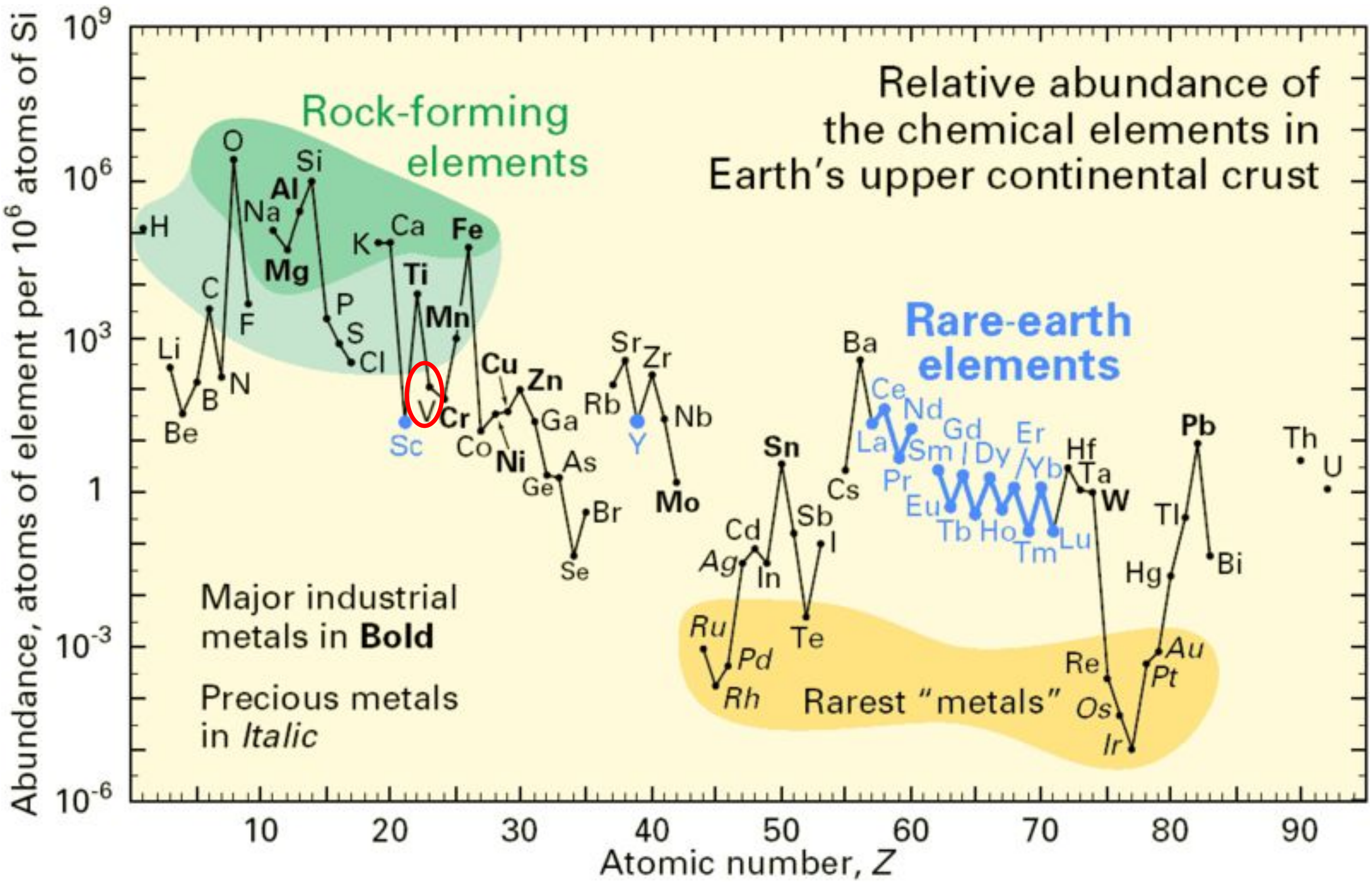
UNIVERSITY of WASHINGTON

References

- Jason B. Quinn *et al* 2018 *J. Electrochem. Soc.* **165** A3284
- University of California Berkeley, Goldman School of Public Policy, *2035, The Report, Plummeting Solar, Wind, and Battery Costs Can Accelerate Our Clean Electricity Future*, June 2020.
- Environmental Earth Sciences. 78. 10.1007/s12665-019-8586-4.
- https://www.tesla.com/models
- https://www.chevrolet.com/electric/bolt-ev
- https://insideevs.com/news/342679/tesla-model-3-2170-energy-density-compared-to-bolt-model-s-p100d/
- http://cleanenergywiki.org/index.php?title=Energy_Basics
- https://www.tesla.com/powerwall
- https://www.pixelsquid.com/png/tesla-powerwall-unit-1467528027649873901?image=G03
- https://www.montereycountyweekly.com/news/local_news/two-projects-would-make-moss-landing-the-energy-storage-capital/article_6e18b50a-8559-11e8-9179-3b23ab89f91e.html
- https://www.statista.com/statistics/201794/us-electricity-consumption-since-1975
- https://electricityplans.com/kwh-kilowatt-hour-can-power/#:~:text=According%20to%20the%20EIA%2C%20in,867%20kWh%20%2F%2030%20days).
- https://southern-energy.com/guide-to-tesla-powerwall/#:~:text=In%20very%20general%20terms%2C%20one,Powerwalls%20is%20a%20good%20start.
- https://www.vectorstock.com/royalty-free-vector/small-cartoon-red-magenta-house-with-trees-vector-31647601
- https://line.17qq.com/articles/gjbebojz.html
- https://www.123rf.com/photo_79405010_stock-vector-blue-aquamarine-tall-building-cartoon-vector-graphic-design.html
- https://www.istockphoto.com/illustrations/wooden-power-pole
- https://www.subpng.com/png-irp4rb/
- https://line.17qq.com/articles/gjbebojz.html
- https://www.eesi.org/papers/view/energy-storage-2019
- https://www.energy-storage.news/news/in-2020-the-us-went-beyond-a-gigawatt-of-advanced-energy-storage-installati#:~:tex
- t=The%20US'%20installations%20of%20advanced,was%20close%20to%203.5GWh.
- https://www.airbus.com/newsroom/news/en/2020/10/hydrogen-fuel-cell-cross-industry-collaboration-potential-for-aviation.html
- https://www.istockphoto.com/search/2/image?phrase=hydrogen+tank
- https://industrial.panasonic.com/ww/products/batteries/secondary-batteries/lithium-ion
- https://batteryuniversity.com/learn/article/bu_210b_flow_battery
- http://cleanenergywiki.org/index.php?title=Storage_Basics
- https://www.energy.gov/eere/water/pumped-storage-hydropower
- https://www.eesi.org/papers/view/energy-storage-2019
- https://www.solagra.com/solar-energy-storage.html
- https://jumbonews.co.uk/uncategorised/2016459/global-redox-flow-battery-market-2020-key-players-list-sumitomo-electric-gildemeister-dalian-rongke-power-ensync-unienergy-technologies-redtenergy-storage/
- https://www.cedigaz.org/clean-hydrogen-building-large-scale-supply-chains/

CLEAN ENERGY INSTITUTE
UNIVERSITY of WASHINGTON

Appendix



https://commons.wikimedia.org/wiki/File:Relative_abundance_of_elements.png