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## **Storing Electricity: Part 2 Technologies**

**(Last edit: 10 AM March 20, 2020)**

Note to readers: Because of the length of this post we are providing a summary so that you may go to portions of the main text for further details. Numerous footnotes are provided with links for additional information.

### **Summary**

We first review the rationale for storing electricity, as discussed in part one of this series. Next, we discuss the use of storage devices that can rapidly respond to what are called 'Ancillary services' - these keep the power delivered to consumers within tight standards.

We then review six different electrical energy storage technologies. Each of them has different capabilities and uses and are in various stages of technological readiness. The two essential characteristics are the maximum rate at which each can deliver power and the duration over which this maximum power rate can be delivered. (The product of these two numbers gives the total energy storage capacity.) These two characteristics are displayed for all six technologies on a single figure, Figure 1. Unfortunately, that figure includes a large number of other technologies (mostly various types of batteries) which are not discussed.

The six technologies discussed are:

1) Pumped hydro storage. (In an appendix we work out an exercise that might appeal to high school physics teachers.)

- 2) ARES (Advanced Rail Energy Storage) A similar technology is described, but one avoiding the need for large reservoirs of water, using as an example the ARES company.
- 3) Compressed Air Energy Storage (CAES)
- 4) Flywheels (Devices rotating at very high speeds, storing kinetic energy)
- 5) Batteries (Especially lithium-ion and flow-through storage batteries.)
- 6) Hydrogen gas (H<sub>2</sub>)

## End Summary

### Rationale for Storing Electrical Energy

In part 1 of this series on storing electricity,<sup>1</sup> we explained how the ability to store the energy from excess solar electricity during the middle of the day, and then convert this energy back to electricity during the early evening hours, could help alleviate two problems:

First, it would allow solar 'farms' to continue producing electricity instead of having to temporarily shut down. Otherwise, added to the amount of electricity produced by various steady and not readily adjustable other sources, it could lead to damaging excess current. Shutting down any source of electrical power, even for a short time, is uneconomical.

Second, without such storage, the absence of sunlight, along with the jump in consumer demand for power during early evening hours, requires otherwise idle gas-fired power plants to 'ramp up' and provide the additional power. Having such plants only on for a portion of every day is likewise uneconomical. In addition, it is undesirable because burning natural gas produces carbon dioxide, adding to global warming.

As an example, in part 1 we estimated that the amount of energy storage that would deal with the 'over-generation' solar problem was around 15.6 gWh (A gWh is a giga-watt-hour or one million kilowatt hours. A kilowatt hour is the usual unit we see in our electricity bills and is typically about 10-15 cents at the lowest rates.) In addition to the daily *total energy* storage capacity, the maximum *rate* of energy storage needed was about 4000 megawatts. We compared these to energy and power outputs from the

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<sup>1</sup> [http://www.centralcoastclimatescience.org/uploads/5/3/8/1/53812733/storing\\_energy\\_part1\\_rw\\_ed.pdf](http://www.centralcoastclimatescience.org/uploads/5/3/8/1/53812733/storing_energy_part1_rw_ed.pdf)

Diablo Canyon nuclear plant, which generates power at a rate of a little over 2000 megawatts and over 24 hours thus generates 48 gWh of energy.

The *daily* storage and retrieval of electrical energy just summarized is one of three *time scales* that storage technology needs to provide.

### “Ancillary Services”

Sudden failures to systems generating electricity, while not common, do occur, and can cause havoc if that power is not quickly replaced. To deal with such a contingency, the California Independent System Operator (CAISO)<sup>2</sup> requires 'spinning reserves'--generating systems connected to the grid but not feeding power to the grid-- but ready to do so as soon as needed. Currently the spinning reserves are mostly in the form of large gas-fired spinning turbines.

But in addition to sudden failures that ‘spinning reserves’ deal with, they constantly provide adjustments to the very fussy electrical grid system. Small fluctuations in either demand or supply can result in a power imbalance that can be damaging to both the supplier’s and user’s facilities. Achieving this moment-to- moment balance is a major task of CAISO.

But there are other issues associated with these fluctuations as well. We want not only the total power delivered to be carefully controlled, but the voltage and alternating current frequency as well. Moreover, the total power traveling down the transmission lines depends on the difference in the 60-cycle timing of the alternating voltage and current (the ‘power factor’). All these short-term requirements are dealt with by what are called *ancillary services*. Those storage technologies that can respond to these needs on a second *time scale*--measured in minutes to fractions of a second--play an important role in making the grid reliable.

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<sup>2</sup> A Visit to Cal-ISO:

Where Does California’s Electricity Come From and How is it Managed?

<http://www.centralcoastclimatescience.org/uploads/5/3/8/1/53812733/ray-weymann-visit-to-california-independent-system-operator-2015.pdf>

There is also a 3rd and much longer time scale, measured in weeks and up to a year, for which storage devices can play a role. Some regions of the country can endure many consecutive days without sun, though California is less vulnerable than most of the rest of the country. And there is far less solar energy available during fall and winter than in spring and summer so storage technologies which have huge capacities could help smooth this large disparity.

### **A Survey of Storage Technologies**

With this overview of the three different storage time scales involved, we discuss some of the storage options available as well as some of the technical and practical issues involved.

Of course, there is also the crucial matter of the costs for any storage technology and how it can be integrated into the electrical grid system. We will discuss this and other economic and political issues in a subsequent post.

Figure 1 displays a variety of storage technologies and their important properties.

## Storage Technology Comparison

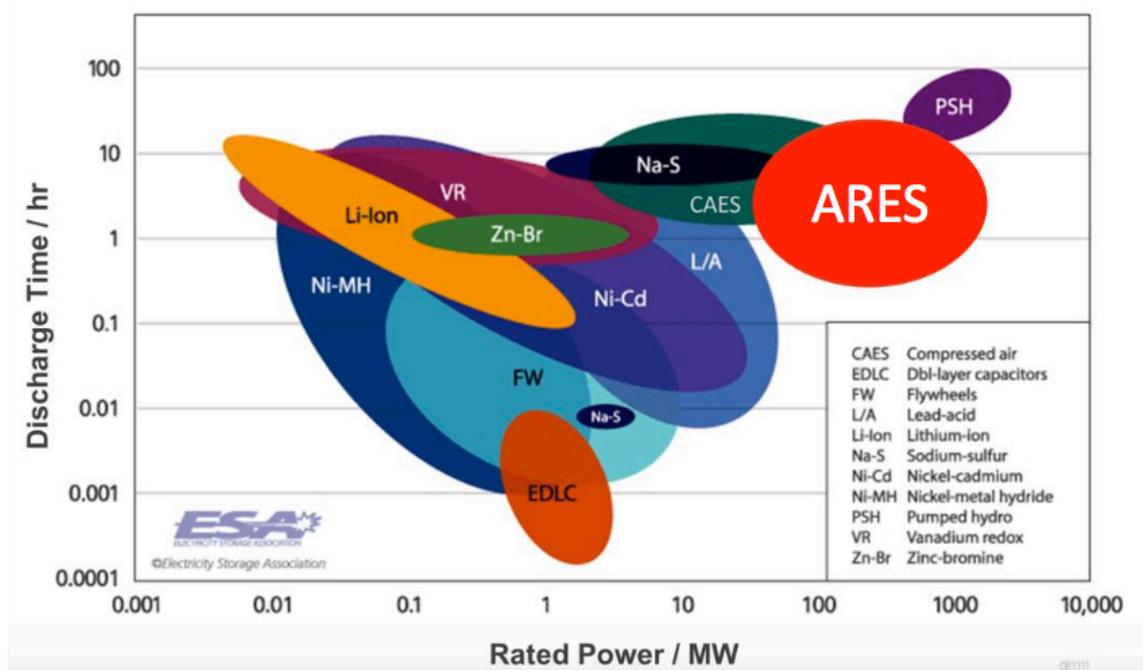


Figure 1. Various electrical energy storage properties. The horizontal axis is the *rate* at which stored energy can be delivered, measures in megawatts, while the vertical axis is the *time* over which this power can be discharged from the storage device. The product of the numbers on the horizontal and vertical axes thus give a measure of the *total energy* that the device stores. Note that recent technology advances make some oval placements in the figure obsolete, as noted in the text. Source: Electricity Storage Association, modified by the ARES corporation, as described in the text.

Many of the ovals in this rather ‘busy’ figure are various types of batteries and we will only discuss one of the them, the “Li-Ion” (lithium-ion) battery in the orange oval shape in the upper left and corner. The other storage technologies of most importance are “PSH”: pumped hydro storage, the purple oval in the upper right, and below it, in the red oval, a variant of this concept, “ARES”, the Advanced Rail Energy Storage company. To the left of the ARES oval is “CAES”, compressed air energy storage, shown as a dark green oval, and finally “FW”, flywheel storage, the light blue oval in the middle.

We briefly consider each of these in turn.

### Pumped hydro storage

Pumped hydro storage currently dominates utility-scale storage both nationwide and in California. An example of a California facility is the Helms Pumped Storage Plant, operated by PG&E, and located about 50 miles east of Fresno. Figure 2 shows schematically the idea.

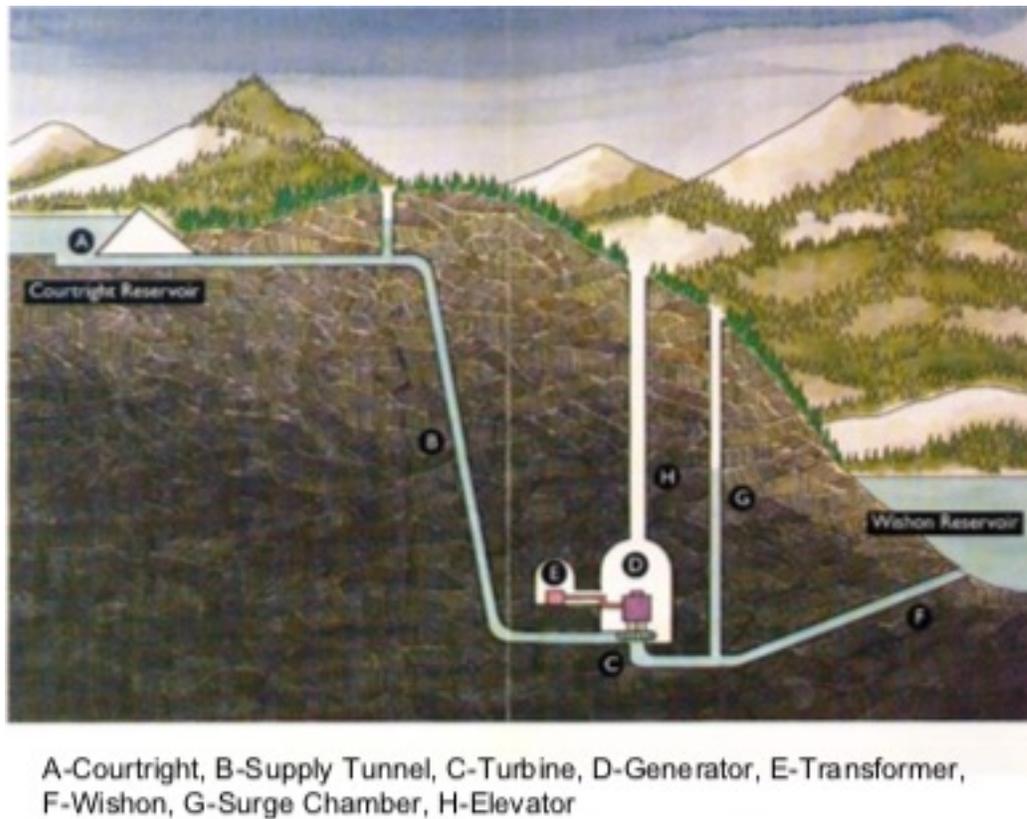


Figure 2. The Helms pumped hydro storage facility. There are two large reservoirs: the upper Courtright reservoir and the lower Wishon reservoir. PG&E sends power to Helms, from generating sources, including the Diablo Canyon nuclear reactors, during times of low demand.

The two reservoirs each store about 125,000 acre-feet of water and have a difference in elevation of about 1750 feet. When there is excess power that can be stored, the water is pumped uphill, storing the energy as *gravitational potential energy*. When electrical power is needed from this source, water is released downhill, the gravitational potential energy is converted to kinetic

energy which in turn drives turbines which generate electrical power. The maximum power output is about 1200 megawatts, consistent with the position of the PSH oval in figure 1. This facility is a 'closed' system meaning that it does not require a very large natural continuous flow to replenish evaporation and other losses and also in that it does not utilize open natural waterways.

The total amount of energy stored in this facility is very large and suitable for the 'daily' time scale. A "just for fun" calculation of the total storage capacity is given in the Appendix. We believe this would be a nice extra-credit problem for high school physics teachers to give to their students!

Expansion of this technology requires construction of new, or conversion of, existing suitable sites and this raises some environmental issues. An excellent story on both the opportunities and challenges involved in expanding pumped hydro storage in California appeared in the Los Angeles Times.<sup>3</sup> Water is of course a precious resource in California and is one of those issues involved in a proposal for new pumped storage, the Eagle Crest pumped storage facility.<sup>4</sup> The facility uses existing mining pits but use water from the aquifer. It is also adjacent to the Joshua Tree National Monument with attendant environmental concerns. Water and environmental concerns are typical of the issues facing new pumped hydro projects, and it remains to be seen what additional pumped storage capacity will be realized in California, but there may be opportunities for using existing paired reservoirs for new pumped hydro projects that would have relatively low environmental impact.

### The "Advanced Rail Energy Storage" Technology

An interesting variant of pumped hydro storage also makes use of storing the energy as gravitational potential energy but instead of water uses heavy material, such as concrete blocks. An example is provided by ARES, the Advanced Rail Energy Storage facility.<sup>5</sup> As shown in figure 3, a car travels up and down an incline on rails. To store electricity, an electric motor takes

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<sup>3</sup> LA TIMES Sunday March 8th: <https://www.latimes.com/environment/story/2020-03-05/is-hydropower-key-to-a-clean-energy-future>

<sup>4</sup> <http://www.eaglecrestenergy.com/project-description.html>

<sup>5</sup> <https://www.aresnorthamerica.com/>

power from the overhead power lines and pushes cars with concrete blocks uphill. The same motor acts as a generator, converting the stored gravitational potential energy to feed power back to the electrical grid, as the cars move downhill. The power and energy storage are less than for pumped hydro, but the advantages of this approach are that there is more flexibility in locating projects to reduce environmental impacts and use of water resources or reservoirs is avoided. Although it is not evident from the ARES oval in figure 1, the system can respond on short enough time scales that it can provide ancillary services as well.

ARES is also developing a variant of the rail car approach, but instead of using motors located within the car, a motor connected to a winch located at the top of the grade pulls the cars uphill and the cable unwinds as they move downhill. This design allows operation on much steeper grades.



Figure 3. The Advanced Rail Energy storage facility being located near Pahrump, Nevada. The facility has a power capacity of about 50 MW and is located next to a major transmission line.

### Compressed Air Energy Storage (CAES)

The basic idea is very simple: When excess power is available, it is used to run air compressors to store air at very high pressures in natural caverns. This high-pressure air can then be used to power turbines to generate electricity. Like all developing technologies however, there are some significant differences in implementing the basic CAES idea.

If you envision a piston (like a bicycle pump) where force is exerted to compress air in an air-tight cylinder, that work will increase the energy of

the mass of air and this increased energy is manifested as increased temperature. But as we all know, heat flows from a higher temperature to a lower temperature, so that some of the work done by the compressor may be wasted as heat escapes. In some versions of CAES, heat may then need to be added (typically by burning natural gas) to warm the air which drives the turbines running a generator. This of course will add CO<sub>2</sub> to the atmosphere. Without this, the cooling of the air by expansion could result in damage from freezing.

In a more sophisticated version of CAES, as the compression takes place, the heat is extracted and stored separately (for example, by heating molten salt) and this heat is then added back during the expansion phase. See this simple short video explaining this concept.<sup>6</sup> While there is a CAES facility in Germany that has been operating for over 40 years, so far CAES projects are still in the planning stage. The efficiencies are not high and suitable sites for storage adjacent to transmission lines are not that plentiful. The most ambitious one we know of is in Utah.<sup>7</sup> The project is reported to have a power output of 1000MW and is a hybrid involving hydrogen burning and batteries as well as the CAES technology.

A study carried out under the auspices of the California Energy Commission reached the following rather pessimistic conclusion as far as a site in California was concerned.<sup>8</sup>

This project demonstrated the feasibility of using a natural gas reservoir for a CAES facility. However, the high cost of a CAES facility is not competitive with the cost of alternative energy storage technologies.

### Flywheel storage

Instead of storing electrical energy by storing it as gravitational energy or compressing air (and thus storing the energy by heating up the air in the process of compressing it), in this technology energy is stored as energy of

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<sup>6</sup> <https://www.youtube.com/watch?v=poGkWZRxVQc>

<sup>7</sup> <https://www.greentechmedia.com/articles/read/utah-aims-to-shatter-records-with-1000-mw-energy-storage-plant>

<sup>8</sup> <https://ww2.energy.ca.gov/2018publications/CEC-500-2018-029/CEC-500-2018-029.pdf>

motion--"kinetic energy". In particular "rotational kinetic energy". The following figure shows the basic idea.

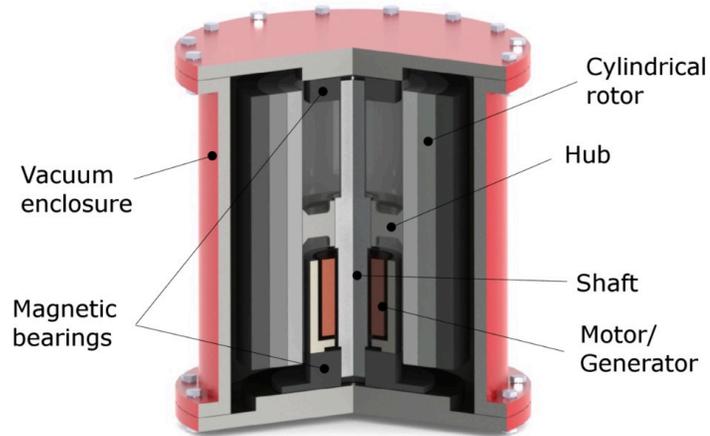


Figure 4. A schematic depiction of a flywheel energy storage system. A motor/generator is mounted inside a vacuum and 'levitated' magnetically. The cylindrical rotor thus has very little friction. Power fed to the motor spins up the rotor to speeds of tens of thousands of revolutions per minute. The stored kinetic energy of rotation can then be used to power the generator mode and send power back to the grid.

A fairly recent detailed study under the auspices of the California Energy Commission explores the potential of this technology for energy storage in California.<sup>9</sup> Here is a brief excerpt from the Executive Summary portion of this study:

The flywheel offers long operating life with no capacity degradation. Additionally, flywheels are capable of many charge/discharge cycles per day (compared to many other energy storage technologies) without any degradation of performance over time, and they can provide ancillary services like frequency regulation, offering grid operators more value from an energy storage device. The technology can be used in a wide range of environmental conditions without using cooling loads, and there is no risk of fire or chemical discharge from this all-steel, recyclable product.

The model studied is the "Amber M32" made by Amber Kinetics. This individual unit can provide power at a rate of 8kW over a 4 hour discharge time, hence a total storage of 32kWh. Comparing this to the pale FW oval of Figure 1, we see that the power rating is well *below* that depicted in Figure 1. We suspect that is due to the fact that a large number of units were assumed when Figure 1 was made. From the

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<sup>9</sup> <https://ww2.energy.ca.gov/2019publications/CEC-500-2019-012/CEC-500-2019-012.pdf>

**report:** "Flywheels are only viable for utility-scale energy storage when multiple units can be integrated into an array to achieve the necessary (grid-scale) storage capacity.

On the other hand, the Amber discharge time is well *above* that depicted in Figure 1. This serves as a warning that storage technology is changing fast. (Indeed, unless similar reports are quite recent they may be misleading concerning any storage technology and its associated costs.)

The Executive Summary concludes with:

#### Benefits to California

This project contributes multiple benefits to California's electricity ratepayers. Any form of energy storage allows the IOU's to add additional solar and wind capacity without risking the need for curtailment. The strategic locating of storage capacity and multi-cycle capability of flywheels can save millions of dollars in transmission congestion costs. There are even larger savings to ratepayers due to the deferral of transmission and distribution system upgrades. Industrial customers can effectively reduce the demand charge element of their electrical bills through a peak shaving strategy. Storing energy to use during peak demand periods reduces the need to add new generating capacity.

The Amber Kinetics flywheels offer many added benefits. The fast system response can provide many benefits to IOU's by stabilizing the local grid and offering ancillary services like frequency regulation. The flywheels are a long-duration, high use, cost-effective solution that does not degrade over time and can operate in a wide range of environmental conditions without heating or cooling which reduces system operating losses and improves reliability. Service reliability to electrical ratepayers can be improved through strategic location of storage facilities. Flywheels have no emissions, consume no water, emit no noise, and have no risk of fire or hazardous material spills making them a good neighbor solution to California's energy challenge.

#### Battery Technology

So far, we have talked about storing energy in several different forms. Batteries involve what is commonly thought of as 'chemical energy'. This is a bit of a misnomer though, since 'chemical energy' really involves the interaction of different kinds of molecules with varying strengths of *electrical* forces binding together each kind of molecule.

The most promising battery technology at present appears to be lithium-ion (Li-I) batteries, though a class of batteries called 'flow-through' batteries has promise. This footnote provides a link to an April 2019 report.<sup>10</sup>

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<sup>10</sup> <https://www.cooperative.com/programs-services/bts/Documents/Reports/Battery-Energy-Storage-Overview-Report-Update-April-2019.pdf>

The Li-I technology has been driven recently by its use in electric vehicles. Rapidly expanding production, as in the case of solar panels, has been accompanied by a steep drop in cost. Further significant drops are very likely. See here<sup>11</sup> and here.<sup>12</sup> Lithium is a rare chemical element with just 3 protons (and either 3 or 4 neutrons) in its nucleus, surrounded by 3 orbiting electrons. The electron in the outer orbit is readily separated from the rest of the atom, and since the electron has a negative charge, this results in a positively charged lithium *ion*. This link provides an animation and shows a schematic Li-I battery.<sup>13</sup> It is lithium ions which carry electric charge back and forth between the anode and cathode. The animation can be paused, and scrolling over it with a mouse shows the basic components.

It should be no surprise though, that this animation leaves out some pretty basic ideas of electro-chemical energy, and so readers who are interested should look at the link in this footnote for a very readable discussion of battery basics.<sup>14</sup>

While Li-ion batteries are a very promising energy storage technology there are safety concerns from overheating and fires. The limited number of times they can be recharged, and the cost of the key materials are also drawbacks, though intensive research is ongoing to minimize these.

Nevertheless, there are projects underway in California to install large banks of Li-I systems. One in Morro Bay will have a power rating of 200MW and combined facilities at Moss Landing will have a power rating of 570MW.<sup>15</sup>

A different battery technology under development involves large tanks of liquid, electrically conducting electrolytes in which the electro-chemically active materials are dissolved. These are called *flow-through* batteries. They have the advantage of very long lives but the disadvantage of having low total energy storage and rates of power production unless they are very large. Thus far they are not cost-competitive with Li-I batteries for grid-scale applications.

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<sup>11</sup> <https://about.bnef.com/blog/battery-pack-prices-fall-as-market-ramps-up-with-market-average-at-156-kwh-in-2019/>

<sup>12</sup> <https://www.nrel.gov/docs/fy19osti/73222.pdf>

<sup>13</sup> <https://www.energy.gov/eere/articles/how-does-lithium-ion-battery-work>

<sup>14</sup> <https://www.science.org.au/curious/technology-future/batteries>

<sup>15</sup> <https://www.sanluisobispo.com/news/local/article238004329.html>

## Hydrogen Storage

A recent article in the February 2020 article of Scientific American describes very well the promise and challenge of this technology and readers interested learning more about it can find it here.<sup>16</sup> This is another example of utilizing 'chemical energy.' As noted above, though, it is really energy in the form of electrical forces binding the two hydrogen atoms together as the hydrogen molecule. This energy is released when 2 H<sub>2</sub> molecules combine with an O<sub>2</sub> molecule to form two H<sub>2</sub>O molecules of water. This energy can be released semi-explosively, as in the famous Hindenburg disaster, a hydrogen-filled blimp which crashed in flames in New Jersey in 1937. Or, it can be released in a controlled way to produce electricity in a *fuel cell*, described in this link from the Department of Energy.<sup>17</sup> In the converse process, *electrolysis*, electrical power is used to separate water molecules into hydrogen and oxygen molecules in *electrolyzers*, as described in this short readable link.<sup>18</sup>

The key questions in this technology are:

- 1) Where do you get the H<sub>2</sub> in the first place? Current production techniques use fossil fuels in its production which defeats the purpose of converting to a non-CO<sub>2</sub> emitting energy economy.
- 2) The second issue is, as always, one of cost. As in the situation with Li-I batteries, current electrolyzers make use of rare and expensive substances. Though this sentence sounds like a broken record, a lot of research is going into finding alternate and less expensive substances to use.

And of course, the presumption is that electrolysis only makes sense in the context of renewable energy, so that the electricity for electrolysis is produced by, for example, solar farms during times of excess solar energy. It is worth mentioning also that some nuclear 'generation IV' designs have specific design goals of the 'co-production' of electricity and H<sub>2</sub>.

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<sup>16</sup> <https://www.scientificamerican.com/article/solar-and-wind-power-could-ignite-a-hydrogen-energy-comeback/>

<sup>17</sup> <https://www.energy.gov/eere/fuelcells/fuel-cells>

<sup>18</sup> <https://www.hydrogenics.com/technology-resources/hydrogen-technology/fuel-cells/>

3) A third major issue is how best to utilize the H<sub>2</sub>. Fuel cells to convert the H<sub>2</sub> to electrical power have already been mentioned, but there are other important applications, including the transportation sector. Although Li-I batteries are preferred for EV cars and light vehicles, long-haul trucking might utilize H<sub>2</sub> in fuel cells. Quoting from the Scientific American article: ..."truck developer Nikola Motor Company says the tractor-trailer rigs it is commercializing will travel about 800 to 1,200 kilometers (500 to 750 miles) on a full fuel cell..."

Another use, already being deployed in France, is for heating buildings and driving turbines for power. Currently the hydrogen is mixed with natural gas, reducing the amount of CO<sub>2</sub> emitted, but ultimately pure H<sub>2</sub> may be utilized.

4) A 4th issue is how to distribute and store the hydrogen. Some natural gas pipelines can be modified to accept hydrogen, but for large scale use new pipeline infrastructure will be needed. The problem posed by storage is that while for a given *mass* of H<sub>2</sub>, the chemical energy locked in it is very high compared to other fuels, at ordinary pressures the *volume* is impractically large. This means that the gas must be highly pressurized which can lead to accidental ruptures. There are proposals for storing huge amounts of H<sub>2</sub> in underground natural caverns. If this is achieved the amount stored might be able to provide weeks-long or even seasonal-length storage to smooth out the seasonal variation of solar energy.

### **Other means of flattening the duck curve**

While electrical storage deployment is certainly an essential component of dealing with the duck curve, it is not the only one. Altering the shape of the demand curve itself will help. One obvious way to do this is to charge customers higher prices when the demand curve otherwise peaks. Another way is to have increased 'grid flexibility', including the ability to export excess solar energy to out of state customers. Electrical cars conceivably could be charged during peak solar time of day at places of work instead of at home during peak times of demand.

Introducing controlled variation in the amount of power generated by sources that normally produce fixed power outputs ('non-dispatchable')

power) is another, and such sources are termed 'load following'. Some nuclear reactors have this capability, but as in the case of the gas-fired 'peaker plants', operating at less than full power is not economical unless the power removed from the grid can itself be stored (e.g. by producing and storing hydrogen gas) or diverted to some other useful application such as water desalinization.

## Appendix: Total energy stored in a pumped hydro facility

The total amount of energy able to be stored in large pumped hydro facilities is suitable for smoothing out the daily 'duck curve'. We illustrate this for the (unrealistic and undesirable) case where we imagine *all* the water in the Helms pumped storage facility's upper reservoir to be drained down to the lower reservoir. This calculation involves the difference in potential energy between all the water stored in the upper reservoir and that when it is drained into the lower reservoir. This is calculated by the difference in potential energy = mass of water \* the acceleration of gravity at the earth's surface \* difference in height, or  $E = M * g * h$

In carrying out this calculation, keeping track of the units is important, and it is best to first convert to the metric system, in particular the "MKS" system, where lengths are measured in meters, mass is measured in kilograms, and time is measured in seconds. In this system of units, the force of gravity (more precisely the *acceleration* of gravity on earth ) is 9.81. Since the numbers get very big we use 'scientific notation' where, for example, 2,000,000 is written as  $2.0 * 10^6$ .

Step 1: There are 43,560 square feet in an acre, so the volume of water in one acre-foot of water is  $43,560 \text{ square feet} * 1 \text{ foot of depth} = 4.35 * 10^4$  cubic feet.

Step 2: Since the amount of water in the upper reservoir is 125,000 acre feet , there are  $1.25 * 10^5 * 4.35 * 10^4 = 5.44 * 10^9$  cubic feet of water.

Step 3: We need to convert this to cubic meters. Since are 3.28 feet in a meter, there are  $3.28 * 3.28 * 3.28 = 35.3$  cubic feet in a cubic meter. So, there are  $5.44 * 10^9 / 3.53 * 10^1 = 1.54 * 10^8$  cubic meters of water.

Step 4. Each cubic meter of water has a mass of 1000 kilograms, so the mass of water, in kilograms, is  $1.54 * 10^8 * 1.0 * 10^3 = 1.54 * 10^{11}$  kilograms.

Step 5: The difference in height from the upper to the lower reservoir is 1750 feet, equal to  $1.75 * 10^3 / 3.28 = 5.34 * 10^2$  meters.

Step 6: Using the formula, potential energy difference = mass\*height difference\*gravitational acceleration on earth, we get  $J = 1.54 * 10^{11} * 5.34 * 10^2 * 9.81 = 8.07 * 10^{14}$  Joules.

We use the symbol J for this energy, standing for "Joules", (named in honor of James Joule, an English physicist (and owner of a brewery.) It is the unit of energy in the MKS system of units. But it is not the ordinary unit of energy which is used in our electricity bills, which is a kilowatt-hour. So:

Step 7. When a Joule of *energy* is consumed or generated in one second, it defines the MKS unit of *power* called the Watt (in honor of James Watt, an engineer from Scotland.) Thus, the energy in Joules transferred from a steady flow of power is equal to the power in Watts times the duration of the flow in seconds. This means that a kilowatt-hour, the flow of power of one kilowatt (1000 Watts) lasting for one hour (3,600 seconds) is equal to  $3.6 \times 10^6$  J. Therefore, the value of  $8.07 \times 10^{14}$  Joules is equivalent to  $8.07 \times 10^{14} / 3.6 \times 10^6 = 2.24 \times 10^8$  kWh or 224 gWh (gigawatt hours), about 4 1/2 days' worth of energy output from the Diablo Canyon nuclear reactors.

Finally, at a power generation rate of 1200 MW = 1.2 gW, dividing the 224 gWh energy storage by 1.2 gW means the reservoir could sustain this power output for roughly 190 hours. This too is in the same general 'ballpark' as the 100 hours at the top of the vertical time axis for pumped hydro.

There are the inevitable losses of energy in converting the stored potential energy and the actual total electrical energy available would have to be reduced by 10 or 15 % or so.