Research Proposal, Low-Carbon Energy Sources

1) Perovskite-Silicon Tandem Panels
2) Diffuse Solar Radiation
3) Grid Enhancing Technologies
4) Salt Batteries for Energy Storage
5) Thermal Batteries
6) Electrostatic Capacitors
7) Long Duration Energy Storage Systems
8) Waste Disposal of Solar Panels
9) Biofuels
10) Domicile Wireless Electricity
11) Solar Energy for Desalination
12) Solar Energy for Water Electrolysis Hydrogen Production
13) Hydrogen Energy, Liquified and Gaseous

Introduction

There are four main types of low-carbon energy: solar, wind, hydro, and nuclear. These are our four options for producing electricity and power in the near future, when we run out of fossil fuels. Like China, I don't believe that global warming and climate change is a big deal, and believe that the world temperature is rising and the arctic ice melting because of normal changes in the Earth's climate as has happened over millions of years. That said, maybe we should not be pursuing the US Democratic Green New Deal so much, but we still need to be spending money researching new power technologies for the time when fossil fuels run out. Plus, it is healthier for the environment to use renewable energy sources or nuclear, it is just not healthy for the economy to rush to change so quickly before the technology is sound. In the US, government taxpayer subsidies constitute a portion of the costs of wind and solar technologies. This is not sustainable, using taxpayer subsidies to pay for electricity.

Two primary issues arise when discussing renewable or intermittent power sources. One, their construction and design, or how do we create renewable energy sources that can produce enough electricity to power our society. Related to this issue, is that of battery storage, and how do we create more powerful batteries to store the renewable energy from the sun and the wind to power our society at nite and on cloudy days? Two, is the pricing of renewable energy sources in the electricity market, as they have low marginal cost. This low marginal cost leads to what is known as the merit order effect of renewable energy sources, whereby conventional fossil fuel energy sources are priced lower. Renewable energy sources have low marginal costs because they have zero fuel costs and only price operations and maintenance into their marginal cost.

One area of research for solar panels is how do we increase the amount of diffuse solar radiation which is utilized by solar panels. Diffuse solar radiation is the solar radiation that is absorbed, scattered, and reflected by: air molecules, water vapor, clouds, dust, pollutants, forest fires, and volcanoes. The solar radiation that reaches the Earth's surface without being diffused is called direct beam solar radiation. The sum of the diffuse and direct solar radiation is called global solar radiation. Atmospheric conditions can reduce direct beam radiation by 10% on clear, dry days and by 100% during thick, cloudy days.[1]

Another area of research for low-carbon systems is the battery design that stores the intermittent energy sources before they are dispatched by power plants for energy to households and businesses. Related to battery design is how do we increase the life of the solar panels. A third area of research is in waste disposal of solar panels and dealing with the dangerous chemicals and minerals that are used to construct solar panels.

In order to move away from nuclear energy in the future, which still relies on rare earth elements to service energy demands, we have to figure out ways to still draw solar energy when the clouds are out, and ways to still harness wind energy when the wind is not blowing. Of these two options, becoming more efficient at utilizing diffuse solar radiation is more feasible than procuring wind when the wind is not blowing. Diffuse radiation is still there, unlike wind power, and we only need to figure out how to harness diffuse solar radiation.

Perovskite-Silicon Tandem Cells

Perovskite PV should be seen as an augmentation to silicon PV. Silicon PV can reliably function for over two decades, whereas perovskite PVs degrade after just a few months to a few years of operation. To make high-purity silicon, temperatures over 1,000 degrees Celsius are needed, and the high temperature comes with higher economic and environmental costs. Perovskites can be produced at lower temperatures, around 200 degrees Celsius, but they degrade when exposed to heat, moisture and air and thus their lifespan is shorter (U Michigan, 2024).

Perovskite solar cells can be tested for stability by exposing them to different outdoor stressors conditions such as humidity, light and heat and under low temperatures. These individual factors act simultaneously in the real-world conditions to affect solar cell performance. When combined, for example, light and heat significantly accelerate performance degradation or cause new problems that were otherwise absent or occurring at slower rates when testing separately. High temperature and illumination is the most important combination of stressors for determining the performance of a perovskite solar cell outdoors. Protocols must first be established so that improvements from different groups can be easily validated and compared.

Advancements in efficiency, lifetime, and resistance have been achieved with solar panels, including both monocrystalline silicon and perovskite. Perovskite solar cells are manufactured from a three-dimensional material called perovskite, with the name originated from the structural form of the original substance, calcium-titanium-oxide, found in the Ural Mountains and commemorated to Russian mineralogist–Lev Perovski. Perovskite solar cells are thin films made of inexpensive and simple perovskite materials, commonly using lead-containing perovskite materials. The light-absorbing layer functions just like the transparent silicon layer, which operates exactly the same way as traditional solar cells. Perovskite solar cells also have a

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[1] Solar Radiation Basics, Department of Energy. Retrieved October 6, 2023.
https://www.energy.gov/eere/solar/solar-radiation-basics

special optoelectronic manner which is favorable for the efficient conversion of sunlight into electricity. Perovskite solar cells can be combined with silicon cells in a two-layered configuration where they complement each other perfectly to produce electricity. The tandem cell has better performance with greater efficiency than the efficiency produced by either cell independently (Garcia, 2024).

Tandem perovskite-silicon solar cells have several key advantages:

1) The proliferation of tandem cells would far surpass efficiencies from existing silicon or perovskite cells which are nearly 30%.
2) With only a thinning perovskite film in a tandem perovskite cell, less lead and other materials are needed compared to in thicker standalone perovskite cells.
3) Tandem cell technology can be used as part of an N-type PV cell manufacturing process that is compatible with the prevailing industry trends.
4) Lower sensitivity to temperature variations can appear – the perovskite top cell also builds efficiency stability in high temperatures.

1) Durability or longevity
2) Efficiency retention when scaled to larger sizes or larger module areas— issues that have hindered their leap from laboratory to commercial viability.

<u>Perovskite Cells Characteristics</u>

1) High efficiency
2) Low manufacturing costs
3) Flexibility of application- ability to be applied to a variety of substrates, from rigid glass to flexible materials.

A US research team looked into the underlying mechanisms that lead to perovskite degradation via the intricate engineering of the nanoscale structure of perovskite solar cells to optimize their efficiency and extend their operational lifespan. They used passivation, which is aimed at stabilizing the material's surface and interfaces. Passivation reduces the degradation of the cells, ensuring that they maintain their efficiency for a longer period. By analyzing and altering the interfaces where the perovskite material meets other components within the cell, new strategies for enhancing stability and performance can be developed (Lewis, 2024).

To make hardier perovskite solar cells, U.S. researchers found that bulky "defect pacifying" molecules are best at increasing the perovskites' stability and overall lifespan. Perovskite crystals contain lead atoms, or undercoordinated sites, that aren't fully bound to the other components within the perovskite, with these defects hindering the movement of electrons and speeding up the decay of the perovskite material. These undercoordinated sites are defects often found on the crystal surfaces and at grain boundaries where there's a break in the crystal lattice. Mixing defect pacifying molecules into the perovskites can help lock up the undercoordinated lead, in turn preventing other imperfections from forming at high temperatures, but we don't know exactly how a given molecule affected the hardiness of perovskite cells, or what features on the molecules specifically improve the perovskite's stability (U Michigan, 2024).

For their experiment, three additives with a range of shapes and sizes were created and added into thin films of perovskite crystals, which can absorb light and convert it to electricity. Size, weight and arrangement were the main properties differentiating the additives, as each additive contained the same or similar chemical building blocks. The different additives were then measured for how strongly they interacted with perovskites and consequently influenced the formation of defects in the films. Larger molecules by mass were better at sticking to the perovskite because they had more binding sites that interact with perovskite crystals, and thus tended to be better at preventing defects from forming. The best additives take up a lot of space, as both the size and configuration are important when designing additives. Large but skinny molecules resulted in smaller perovskite grains during the manufacturing process. Smaller grains aren't ideal because they also create perovskite cells with more grain boundaries, or more areas for defects to form. In contrast, bulky molecules forced larger perovskite grains to form, which in turn reduced the density of grain boundaries in the film. The perovskite films were heated to over 200 degrees Celsius to confirm that bulky additives help the films retain more of their characteristic slate black color and develop fewer structural defects (U Michigan, 2024).

Diffuse Solar Radiation

1) Global, direct and diffuse components of solar radiation
2) Temperature, relative humidity and wind speed
3) Hourly, daily and monthly basis

1) Compare experimental data to the predictions of different theoretical models as functions of declination and hour angles
2) Obtain correlations describing the variation of hourly, daily and monthly averages of total and diffuse solar radiation using polynomial expressions
3) Obtain empirical correlations describing the dependence of the daily average diffuse to total radiation ratio on the clearness index
4) Compare data for the daily diffuse to total radiation ratio to correlations obtained by other investigators

In a form of geoengineering, the deliberate manipulation of Earth's natural processes to tweak its climate and weather conditions, gigantic solar farms could bring water relief to desert communities. In this scenario, dark-colored solar photovoltaic panels absorb heat and, if large enough in scale, can create "artificial heat islands" in local areas. If the desert community has a sea breeze, the warmth could be drifted upwards via convection and promote cloud formation in the skies. Computer models suggest that a 10-kilometer square (3.8 square miles) field of black solar panels would have very little impact on rainfall. A 20-square-kilometer (7.7 square miles) solar panel field would create around 570,000 cubic meters each day of rain. If this occurred for just 10 days in a year, it could provide enough water for over 31,000 people annually. A 50-square-kilometer (19 square miles) solar field, this would create enough rain to provide

125,000 extra people with water each year. However, this solution might not work for every region of the world that's facing water stress, as a 2020 Sahara study shows that although it would increase rainfall in the local area, it would have a profound knock-on effect across the globe, causing droughts and forest degradation in the Amazon, as well as temperature increases and sea-ice loss in the Arctic (Chapman, 2024).

Grid Enhancing Technologies

As more renewable energy comes online, grid operators need to facilitate the delivery of more wind and solar without building new lines. This would save customers money and reduce electricity costs. However, regulated utilities make more money by building more generating stations, and transmission lines, as everything they build has a fixed return on investment set by regulators. Therefore, there is little incentive for utilities to increase transmission line capacity with magic balls. Consider altering a power line to carry 40% more electricity, which means that a transmission line that normally carries 1 MW of electricity could now carry 1.4 MW. Heimdall Power of Norway produces a sensor called a Neuron, which is known in the industry as a "magic ball." The magic balls cost $6,000 dollars each, are the size of a bowling ball, weigh 8 pounds, can be fastened to power lines using a drone, are more common in Europe than in the United States, and are referred to as a grid enhancing technology. A Neuron wraps around a high voltage transmission line and reads its temperature, then shares those readings in real time with the operator of the transmission line. The sensor operates using electricity it draws from the line to measure its temperature. Transmission lines get hotter as the amount of power they are transmitting increases. By knowing the precise temperature, or speed limit, the grid operator knows how close the line is to maxing out on its capacity using a neuron speedometer. Power companies have traditionally set limits on the flow of power on a seasonal basis, rather than in response to real time conditions, like they could using a magic ball. By knowing exactly how much power a line can handle, an operator can increase the flow of power for hours or even days to get closer to the limit than otherwise would happen (Hanley, 2024).

Salt Batteries for Energy Storage

Jules Verne used a sodium battery to power Captain Nemo's submarine in his 1870 novel 20,000 Leagues Under the Sea. Rechargeable liquid-metal batteries such as lithium-ion are used for industrial power backup, electric vehicles and for grid energy storage. Sodium batteries have garnered more research in recent years as the mining and environmental impacts of lithium batteries have become more consequential. Lithium, which can be costly to mine, is currently the main component in most electric batteries. Lithium extraction can result in water shortages, biodiversity loss, damage to ecosystem functions and soil degradation. When lithium is produced using evaporation ponds, for example, it takes approximately 2.2 million liters to produce one metric tonne (Elton, 2022). Lithium has uneven geographic distribution, high environmental impact, and high cost. Future batteries could run on sulfur or sodium, which are more abundant than lithium on the planet. However, because sulfur reacts to oxygen, sulfur-based batteries would need to be manufactured in oxygen-free environments. Solid-state batteries are another option, which use solid instead of liquid electrodes and electrolytes. The more power you can pack into smaller cells, the farther electric vehicles can travel between charging points, and thus have a lower cost.

One benefit of batteries is to store summer heat to use during winter, and there are many different types of salts to choose from for sodium-ion batteries. Sodium or lithium is the cathode, or charge carrier, and both of these elements are in the same group in the periodic table, and thus have similar characteristics. However, aqueous sodium batteries are different from lithium batteries. Solar panels convert light from the sun into energy, but the solar panels also are heated by the sun, and this heat can be stored with salt batteries. Lian Blijlevens of Radboud University said, “The heat can be extracted by a solar boiler and used to heat your house or shower. However, in summer you always generate more solar heat than you use, and in winter you have less. So what we need is a way to preserve that heat (Radboud University, 2023).” Batteries are increasingly needed to store energy from intermittent renewables like wind and solar. Many batteries are presently built with rare earth metals like lithium, graphite, and cobalt. To achieve climate neutrality, the EU will require 18 times more lithium than it currently uses by 2030 and almost 60 times more by 2050. European Commission President Ursula von der Leyen said in September 2023 that "lithium and rare earths will soon be more important than oil and gas (Elton, 2022)."

Sodium (Na) can be used for the negative electrodes in a rechargeable battery. The sodium must be in liquid form, with the melting point of sodium being 98 °C (208 °F). Thus, sodium-based batteries operate at temperatures between 245 and 350 °C (470 and 660 °F) (Buchmann, 2011). Metal combinations with operating temperatures at 200 °C (390 °F) and room temperature are also research areas. Sodium-ion battery (SIB) cells consist of a cathode based on a sodium-based material, an anode (not necessarily a sodium-based material) and a liquid electrolyte containing dissociated sodium salts in polar protic or aprotic solvents. To charge a sodium-ion battery, the sodium ions move from the cathode to the anode while electrons travel through the external circuit. During discharge, the reverse process occurs, with the sodium ions moving from the anode to the cathode.[2]

Molten-salt batteries have four times the energy storage capacity as lithium batteries, use molten salts as an electrolyte, and offer both a high energy density and a high power density. Molten salt batteries have been around since 1970, but they have a short energy life cycle, so one way to improve sodium-sulfur batteries is to alter the electrodes to improve the reactivity of the sulfur.[3] The chemistry of salt batteries has long been known, but what is still being researched is which salts are best for use in homes. "A salt battery contains salt hydrates, which are salts with water in the crystals. The battery recharges by heating the salt, which causes the water to go out of the crystals. When you need the heat, you add water vapor to the crystals and the heat is released again," says Blijlevens. "If you want to heat a house this way, you need about 10 m^3 of material, which corresponds to two to three wardrobes. You no longer need natural gas and you can use the heat you store in summer in winter. It's a great solution to a major problem (Radboud University, 2023)."

Procedure

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[2] https://en.wikipedia.org/wiki/Sodium-ion_battery
[3] https://en.wikipedia.org/wiki/Molten-salt_battery

1) Assess hundreds of salts on availability, safety, and compactness
2) The dozen or so salts that made it through the initial assessment are then tested in the lab for recyclability. You don't want to have to replace the salt every year
3) Test the salts using thermal analysis: place the salt on heated scales and increase the temperature. You can see the weight of the salt change, which shows that the water is evaporating out of it. If you then add water vapor again at a lower temperature, you can see how much water is being absorbed.

A salt is an ionic compound, organic or inorganic, formed by the neutralization reaction of an acid and a base. Cations and anions in related numbers form a salt so that the product is electrically neutral and made up of two groups of oppositely charged ions. Salts dissolve in water and their ions dissociate into positively charged cations and negatively charged anions, which makes ionic solutions ideal electrolytes that can conduct electricity.

Neutralization Reaction

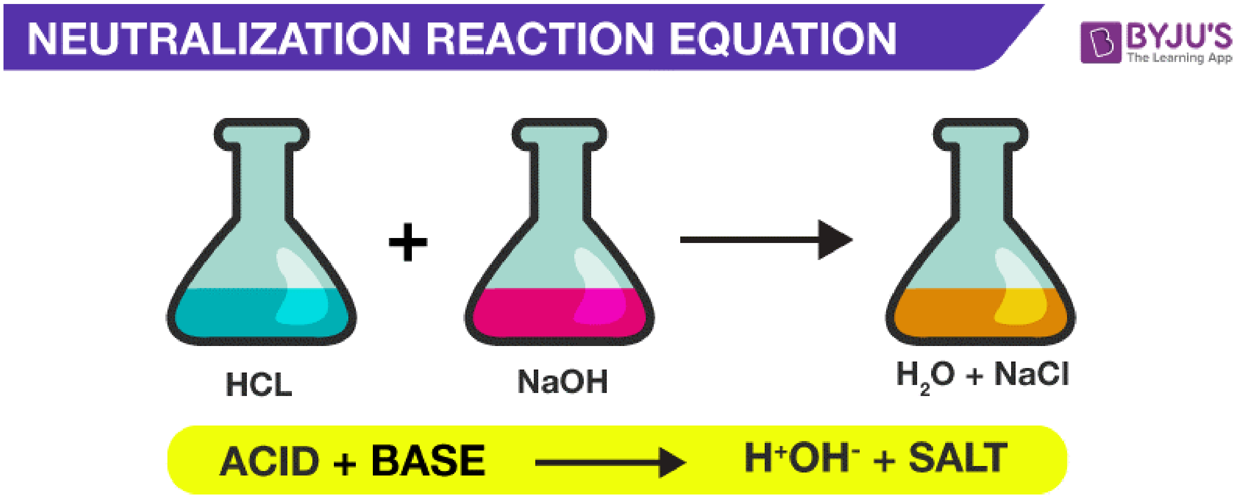
$HCl + NaOH \rightarrow NaCl + H_2O$

A neutralization reaction between acidic hydrochloric acid and basic sodium hydroxide, forming table salt and water. This is a double replacement reaction where the anions and cations exchange partners.

Combination Reaction

$2Na + Cl_2 \rightarrow 2NaCl$

Salts can also be produced through combination reactions, such as sodium chloride, where metallic sodium, an alkali metal, and gaseous chloride, a halogen, combine in an exothermic reaction. .



BYJU'S, What is a Neutralization Reaction?, https://byjus.com/chemistry/neutralization-reaction/

Neutralization Reactions

1) Titration Methods
2) Wastewater Treatment
3) Nanomaterial Synthesis
4) Digestive Systems
5) Controlling Soil pH

Salts are used in manufacturing products like fertilizers, dyes, and polyester fabrics. Salts also serve a biological function in living organisms, including maintaining cellular integrity and controlling the balance of water and nutrients through turgor pressure. Salt serves as an electrolyte that enables neural signals to be transmitted by the brain to the muscles and organs, and vice-versa, electrochemical signals such as nerve impulses. Too much salt in drinking water makes the water unsafe, and fertilizer salts can runoff into the water system causing eutrophication, which is when algae blooms and overproduction of bacteria that feed on the decomposing algae, which depletes the amount of dissolved oxygen in the water, killing marine organisms.

Properties of Salt

1) Crystalline Lattice Structure
2) Ionic Bonds
3) Taste
4) Color- can be transparent, translucent, or opaque, depending on structure of monocrystals and ionic composition. Salts exist in many different colors, which arise either from their constituent anions, cations or solvates.
5) Odor- neutralization reactions from strong acids and strong bases do not have odors. Weak acids and strong bases and vice versa have odors.
6) Solubility- ionic compounds which are highly soluble in water and other solvents
7) Conductivity- Due to ionic and polar properties, molten salts and salt solutions conduct electricity
8) Melting point- high melting points due to strong ionic bonds. Table salt 801 degrees Celsius.

1. Table Salt

Table salt is commonly what people think of when they say “salt.” It has very fine grains. Table salt can be produced through mining or evaporation. But it is further processed. It gets purified of trace minerals and contains added potassium iodide and caking agents to prevent clumping.

2. Kosher Salt

How many types of salt are there in the world? Surely, kosher salt is one of the most notable salts in that list. The most distinguished feature of kosher salt is its coarse texture. Compared to table salt, kosher salt has larger crystals and does not contain additives. Moreover, it dissolves easily. Wondering why it’s called “kosher”? You may take interest in our article “Kosher Salt: What’s special about kosher salt? Why It’s Called Kosher?”

3. Sea Salt

Sea salt, as the name suggests, is produced by the evaporation of seawater. All sea salt is not the same. The mineral content and evaporation methods vary depending on the area the salt is produced. Sea salt has been used by humans since prehistoric times. It is commonly used today as well for not only culinary purposes but also in baths, body scrubs, and some beverages.

4. Lake Salt

It is similar to sea salt, but the salt derived from salt lakes is almost perfectly pure. Largest Salt Lake in the world is Great Salt Lake in Utah, United States. There is a Salt Lake in Central Anatolia, Turkey as well. We can say that the most natural salt type is lake salt since it does not contain any heavy metal and chemical impurities. Lake salt can be different grain sizes like fine salt, extra fine salt and coarse salt which gives nice flavour to your food. It’s also consumed as not only table salt or food salt but also industrial salt and animal salt.

5. Pink Salt

Another one of the different types of salt in the world is pink salt. As its name points out, one of the notable types of salt, pink salt is known for its pink hue. The most known version of pink salt is the Himalayan which is mined in Pakistan. There is also a lesser-known version of pink salt which is the Bolivian. Pink salt is chemically quite similar to table salt although they differ a lot in terms of appearance. Pink salt contains 98% sodium chloride just like table salt. Other trace minerals, such as potassium, magnesium, and calcium which constitute the rest of pink salt, give it the pink hue. It is commonly used in cooking and seasoning just like table salt.

6. Gray Salt (Sel Gris)

Gray salt is harvested by hand from clay-lined pools. Sel Gris is produced from the salt ponds in the Guérande region of France. It is the clay in the pools that gives the salt crystals a gray color. The clay suffuses the salt with minerals such as calcium, manganese, and iron. Gray salt has a flaky and soft texture. Additionally, Sel Gris has natural moisture to itself.

7. Fleur de sel Salt Flakes

Here goes another one on the list of “how many types of salt are there in the world?” Fleur de sel is quite an expensive and rare type of salt. It is harvested from the thin crystalized layer that rises to the surface of the saltwater ponds in the shallow seawater of the Brittany coast in France. Compared to table salt, it contains less sodium and more minerals and has a briny flavor. Fiore di Cervia, the Italian version of Fleur de sel, is produced in the same way, but as the water differs, it is less briny and contains fewer minerals. It is known as flake salt and its crystals are typically shaped like pyramids, thin and light. Also flake salt is low on minerals.

8. Himalayan Black Salt

Another notable one of the different types of salt in the world is Himalayan black salt which is actually purple-red in color rather than black. However, its original name kala manak means “black salt.” Its color comes from the mineral greigite. Also, Himalayan black salt contains sulfur which gives it a harsh smell. Moreover, it has a square crystal structure.

9. Hawaiian Black Lava Salt

How many types of salt are there in the world? Hawaiian black lava salt is surely an outstanding one in the list. Yes, you’ve read it right, Hawaiian black lava salt is harvested through the evaporation of pools on hardened lava flows. After the harvest, the salt is mixed with activated coconut charcoal. It may have a slight sulfur aroma to itself.

10. Hawaiian Red Salt (Alaea Salt)

Alaea salt gets its name from the clay that is rich in iron oxide ‘alaea’ which is mixed with the harvested unrefined sea salt. This red volcanic clay gives the salt its characteristic brick red color. Historically, Hawaiian red salt has been used for religious ceremonies. It is also used in various native Hawaiian dishes.

11. Truffle Salt

Truffle salt is another one on the list of “how many types of salt are there?” It is one of the most common flavored salts. Truffle salt can have different versions depending on the mixture of black or white truffles with different types of salt.

12. Pickling Salt

Pickling salt is mostly used for pickling purposes. It has a coarse texture and does not contain iodine, minerals, or anti-caking ingredients. It also has fine granules which make it easier to dissolve in brine when pickling.

13. Celtic Grey Sea Salt

Celtic grey sea salt is harvested from the tidal ponds in the Celtic Sea, off the coast of France. It gets its grey color from the minerals that are left after the seawater is evaporated.

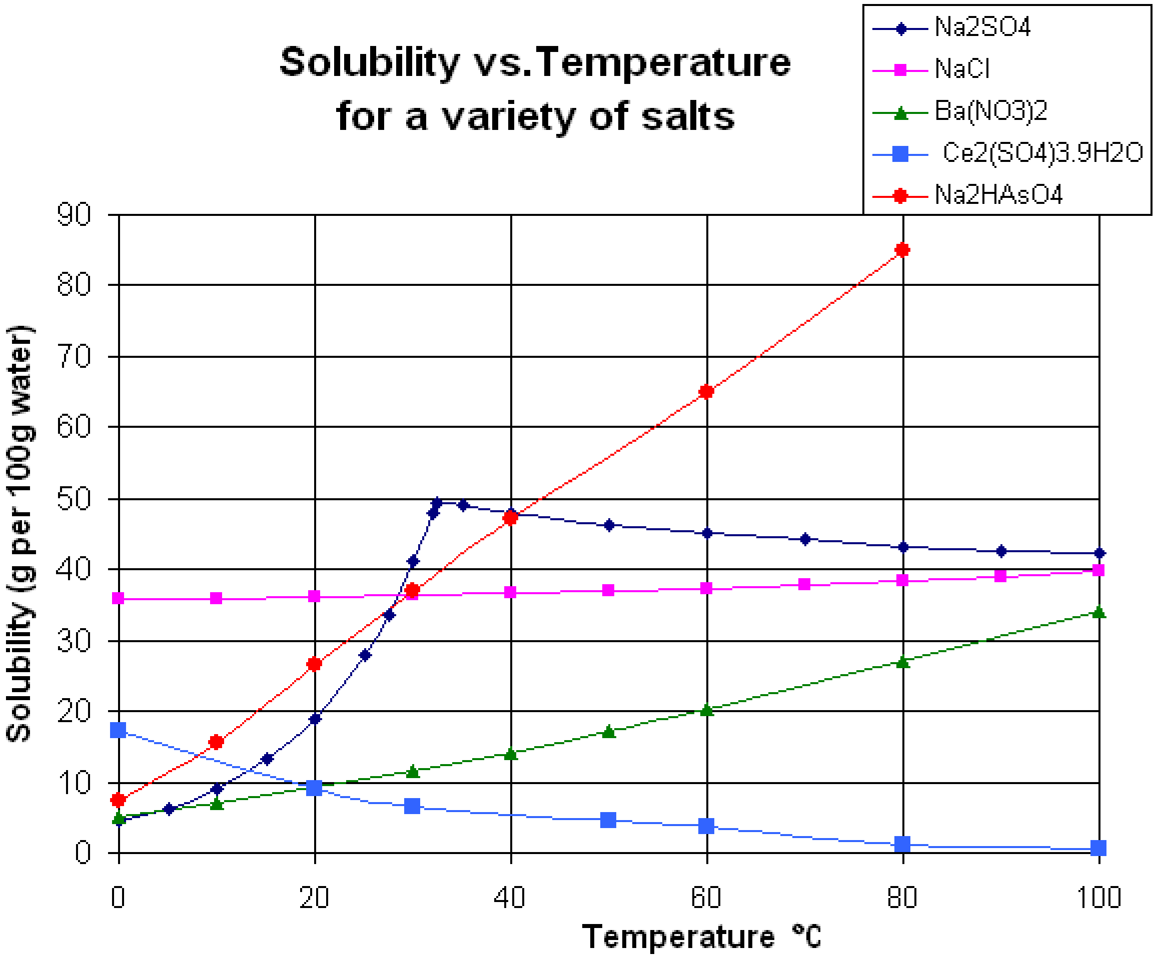
Being another one of the different types of salt, flake salt is also harvested through the evaporation of the seawater just like grey salt. However, the difference is its shape and texture. Its crystals are typically shaped like pyramids, thin and light. Alos, flake salt is low on minerals.

14. Smoked Salt

How many types of salt are there in the world? Certainly, a lot, especially when the flavored salts are added to the list. Smoked salt is produced by a cold smoking process with wood like apple, alder, or hickory. As the wood for smoking the salt and duration varies, so do the color and flavor.

15. Cyprus Black Lava Salt

This one of the different types of salt resembles Hawaiian black salt. However, it is harvested from the island of Cyprus in the Mediterranean Sea. It forms through natural solar evaporation. Moreover, it is mixed with activated charcoal.



Types of Salt

1) Simple Salts
2) Acidic Salts- strong acid and weak base
3) Basic Salts- strong base and weak acid
4) Neutral Salts- strong acid and strong base
5) Double Salts- formed from the reaction of two simple salts that crystallized in the same ionic lattice. Double salts have more than one type of cation or anion.
6) Complex Salts
7) Mixed Salts

A) Sodium Chloride- NaCl, simple salt, colorless or white because the constituent cations and anions do not absorb light in the part of the spectrum that is visible to humans. Used in the chemical manufacturing industry to produce other chemical products such as: sodium bicarbonate, sodium hydroxide, chlorine, and hydrochloric acid. Used in soap and porcelain enamel manufacturing and metallurgical processes, as the salt encourages metals to fuse.
B) Sodium Carbonate- NaHCO_3, acidic salt

C) Ammonium Chloride- NH_4Cl, acidic salt

D) Sodium Acetate- $NaOOCCH_3$, basic salt

E) Potassium Cyanide- KCN, basic salt

F) Zinc Chloride Hydroxide- Zn(OH)Cl, basic salt

G) Potassium Chlorate- $KClO_3$, neutral salt

H) Calcium Phosphate- $Ca_3(PO_4)_2$, neutral salt

I) Sodium Nitrate- $NaNO_3$, neutral salt

J) Potassium Cerium Flouride- $KCeF_4$, double salt

K) Mohr’s Salt- $(NH_4)_2Fe(SO_4)_2 6H_2O$, double salt

L) Tetra Amino Cupric Sulfate- $([Cu(NH_3)_4]SO_4)$, complex salt

M) Hexamine Chromium (III) Chloride- $[CR(NH_3)_6Cl_3]$, complex salt

N) Bleaching Powder- $(Ca(ClO)_2)$, mixed salt

O) Sodium Potassium Sulphate- $(NaKSO_4)$

P) Strontium Chloride: not too expensive, heats up well, and remains stable without side effects. Strontium chloride (SrCl2) is a typical salt of strontium and chlorine, and is considered an ionic metal salt. It's a white crystalline solid with no odor that's soluble in water and slightly soluble in alcohol. It has a melting point of 874°C and a boiling point of 1250°C. It is a 'typical' salt, forming neutral aqueous solutions. As with all compounds of strontium, this salt emits a bright red colour in flame, and is commonly used in fireworks to that effect.

Q) Potassium Carbonate: is cheaper, but this salt also reacts to CO2, which makes the battery less effective in the long run. Potassium carbonate (K_2CO_3) is an inorganic salt that is a white powder that is soluble in water and forms a strongly alkaline solution. It is also known as carbonate of potash, dipotassium carbonate, pearl debris, salt of tartar, or pearl ash. It is a carbonate salt and a potassium salt. Potassium carbonate (K2CO3) is a white salt, soluble in water (insoluble in ethanol) which forms a strongly alkaline solution. It can be made as the product of potassium hydroxide's absorbent reaction with carbon dioxide. It presents a large capacity to absorb moisture. Sodium carbonate and potassium carbonate are the most widely used alkaline salts nowadays, most commonly a mixture of the two.

R) Sodium Sulfur: can be processed from seawater. Sodium sulfide (Na2S) is an inorganic sodium salt and sulfide salt that forms when sodium (Na) reacts with sulfur (S). It is a yellow to brick red solid that smells like rotten eggs. Sodium sulfide is found in gel form, where it softens toenails to help with trimming and relieve pain from ingrown toenails. Sodium sulphate is the sodium salt of sulphuric acid. When anhydrous, it is a white crystalline solid, the decahydrate Na2SO4□10H2O has been known as Glauber's salt. Sodium sulphate is mainly used for the manufacture of detergents and in the Kraft process of paper pulping.

S) Sodium Sulfate- Sodium sulphate $Na_2(SO_4)$ is formed by a reaction between sodium hydroxide and sulphuric acid which are strong base and acid, respectively. Thus, it is a neutral salt with a pH of 7.

T) Barium Nitrate- Ba$(NO3)_2$, Molecular Weight 261.34 g/mol, Barium nitrate appears as a white crystalline solid. Noncombustible, but accelerates burning of combustible materials. If large quantities are involved in fire or the combustible material is finely divided, an explosion may result. May explode under prolonged exposure to heat or fire. Toxic oxides of nitrogen produced in fires. Barium nitrate is an inorganic nitrate salt of barium. It is an inorganic barium salt and an inorganic nitrate salt. Used to manufacture barium oxide (BaO2); in pyrotechnics for green fire; for green signal lights; in vacuum tube industry; for ceramic glazes; in electronics; as raw material for manufacture of neon sign lightings; in tracer bullets, primers, and detonators. Melting Point 592 degrees Celsius. Boiling Point 83 degrees Celsius.

U) Cerium(IV) Sulfate Nonahydrate- $Ce_2(SO_4)_3 9H_2O$, sulfuric acid, cerium salt

V) Disodium Hydrogen Arsenate- Na_2HAsO_4 The salt is the conjugate base of arsenic acid. It is a white, water-soluble solid. Disodium hydrogen arsenate is highly toxic. Being a diprotic acid, its acid-base properties is described by two equilibri.

W) Monopotassium arsenate- KH_2AsO_4 is the inorganic compound. A white solid, this salt is used to prepared other arsenic-containing compounds, mainly pesticides. It is prepared by calcining arsenic oxide and potassium nitrate, followed by extraction with water. Relevant acid-base equilibria for aqueous solutions of this diprotic acid derived from arsenic acid are as follows:

X) TriSodium Arsenate- Na_3AsO_4 is the inorganic compound. The trisodium salt is a white or colourless solid that is highly toxic. It is usually handled as the dodecahydrate Na3AsO4.12H2O.

Y) Sodium Dihydrogen Arsenate- NaH_2AsO_4

Z) Sodium Chromate- Na_2CrO_4 is made yellow by the chromate ion CrO_4^{2-}

AA)Potassium Dichromate- $K_2Cr_2O_7$ is made red-orange by the dichromate ion $Cr_2O_7^{2-}$

BB)Cobalt (II) Nitrate Hexahydrate- Co$(NO_3)_2$·6H_2O is made red by the chromophore of hydrated cobalt(II) [Co$(H_2O)_6$ $]^{2+}$

CC) Copper (II) Sulfate Pentahydrate- CuSO_4·5H_2O is made blue by the hydrated copper(II) cation.

DD) Potassium Permanganate- KMnO_4 is made violet by the permanganate anion MnO_4^-, used in treating some skin conditions like fungal infections. Used in synthesizing organic compounds like ascorbic acid.

EE)Nickel (II) Chloride Hexahydrate- NiCl_2·6H_2O is made green by the hydrated nickel(II) chloride [Ni$Cl_2(H_2O)_4$].

FF) Magnesium Sulfate Heptahydrate- Mg$SO_4 7H_2O$, colorless or white because the constituent cations and anions do not absorb light in the part of the spectrum that is visible to humans.
GG) Anhydrous Cobalt (II) Chloride $CoCl_2$
HH) Cobalt(II) Chloride hHexahydrate, $CoCl_2 \cdot 6H_2O$
II) Lead Diacetate- sweet tasting but poisonous
JJ) Magnesium sulfate- bitter taste
KK) Potassium Bitartrate- sour
LL) Monosodium Glutamate- savory flavor, highlights the taste of other food ingredients
MM) Cobalt nitrate- red due to presence of hydrated cobalt (II)
NN) Copper sulfate- blue due to copper (II) chromophore
OO) Hydrogen Cyanide- cyanide salt, smells like an almond
PP) Ammonium Hexachloroplatinate- not soluble
QQ) Potassium Cobaltinitrate- not soluble
RR) Metal Carbonates- not soluble
SS) Sodium hypochlorite- cleaning and bleaching agents
TT) Alum- water treatment, used to remove mineral particulates
UU) Sodium Nitrate- used in manufacturing of explosives and fertilizers
VV) Potassium Chloride- fertilizer salt
WW) Potassium Sulfate- fertilizer salt
XX) Tetra Amino Cupric Sulfate- used in manufacturing artificial fabrics, like cuprammonium rayon.
YY) Zinc Chloride Hydroxide Monohydrate- feed additive and nutritional supplement for domesticated animals. Antifungal component for treating plants.
ZZ) Lithium salts are a key component of battery electrolytes. Lithium hexafluorophosphate (LiPF6) is the most common lithium salt used in commercial rechargeable lithium-ion batteries (LIBs). Lithium salts are made up of an inorganic anion and a lithium cation, which is responsible for the lithium conductivity in the system. Lithium salts are important because they: Ensure ionic conductivity, Provide electrochemical and thermal stability, Prevent corrosion, and Affect the cyclability of the battery.
AAA)

https://www.pyrochemsource.com/
https://pubchem.ncbi.nlm.nih.gov/
https://byjus.com/
https://en.wikipedia.org/wiki/Salt_(chemistry)

Benefits of Using Sodium in Batteries

1) High reduction potential of −2.71 volts
2) Low weight
3) Relative abundance
4) Low cost

Lithium-ion Batteries Shortcomings

1) Shortage of raw material resources, supply chain issues- Chile and Australia.

2) Thermal Runaway, Catching Fire- Lithium-ion batteries rely on a liquid electrolyte solution in order to charge and discharge the battery properly. It does this by moving lithium ions between the positive side (cathode) and negative side (anode) of the battery, acting as a middle man of sorts. The problem is that this electrolyte is flammable. Lithium-ion batteries don't play well with heat. If a battery cell starts to overheat, pressure will build up within the cell and open the pressure release port. These release ports are to help release the pressure and keep the battery from exploding. However, what gets released is a flammable gas vapor that could potentially catch fire. This spreads to the other battery cells and forms a chain reaction.
3) Environmental Costs- Mining the lithium carries some downsides for the environment and areas where it's extracted, due to the water and energy resources needed. Lithium is extracted from salty water brines found underground or on the surface, with the liquid pumped from the earth and divided into large pools and left to sit so the water can evaporate, leaving behind lithium and other materials. Lithium mining pollutes our air and water, with the mining process taking up land and water resources.
4) Most of the equipment necessary to operate the lithium mines are powered by fossil fuels.

Advantages of Lithium-ion Batteries

1) Energy Density- Lithium-ion batteries are currently the most energy dense batteries we have on the market. Energy density is the amount of energy you're able to store in a given amount of space.
2) Cycle Life- Rechargeable.
3) Cost- Scientists have found chemically compatible and cheaper materials, while engineers continue to pack more of those materials into the same space.
4) Nickel is used to increase the energy density of the battery.
5) Cobalt is used to stabilize the energy density of the battery. DR Kongo
6) Manganese over Cobalt- A widely abundant resource and a safer alternative than a battery packed with high concentrations of nickel. Increase manganese, get rid of the cobalt and decrease nickel content.

Advantages of Sodium-ion Batteries

1) Raw material reserves of sodium-ion batteries are abundant, easy to extract, low cost, 500 times more abundant than lithium.
2) Better performance at low temperatures.
3) Advantages in large-scale energy storage- the cost can be reduced by 20 percent to 30 percent from lithium-ion batteries, and the cost per kWh of electricity can be reduced to RMB 0.2 ($0.0276)
4) Increased lifespans
5) “Chemical kinship” between sodium and lithium provides information for battery research in design and fabrication techniques. Sodium is just below lithium in the periodic table of the elements, meaning their chemical behaviors are very similar.
6) Safer than lithium-ion batteries, do not combust

7) Safer than lithium-ion batteries, and can be discharged to 0V – eliminating the possibility of thermal runaway due to a short circuit.
8) Sodium-ion also opens up new opportunities for scientists to experiment with new elements and materials that didn't play nice with lithium. This allows for the increase in manganese and iron content in the battery cathode. Both of which are cheaper and more sustainable than nickel and cobalt.
9) New non-flammable electrolytes, potentially even new solid-state electrolytes.

Disadvantages of Sodium-ion Batteries

1) Longer charging times- Quick charging is needed for electric vehicles. Range anxiety—stemming from the lengthy duration required to recharge batteries.
2) Lower energy density, lower power output. Energy density is the amount of juice that can be stored in relation to the battery's mass or volume.
3) Weight- Sodium is a heavier element than lithium, creating issues for use in electric vehicles, but being more suitable for use in grid-scale storage operations.
4) Degradation- The protective film on the anode of a sodium-ion battery degrades over time. This film is critical because it allows sodium ions to pass through while preserving battery life. Lithium-ion batteries also degrade, but a typical sodium-ion battery degrades much faster. Developing an electrolyte formula that stabilizes the film has been a moving target.
5) Shorter cycle life

Similarities Between Sodium and Lithium Batteries

1) Similar electrochemical mechanisms, both realizing energy storage and release through the reversible disengagement and embedding of cations between the positive and negative electrodes.
2) The anode of both types of batteries is carbon, with the difference that the cathode material of lithium-ion batteries contains lithium ions, while the cathode material of sodium-ion batteries contains sodium ions.
3) The lithium salts in the electrolyte (the liquid that helps ferry charge between the battery electrodes) are traded out for sodium salts.

Sodium Batteries

1) When charging, sodium ions are discharged from the positive electrode of the battery and enter the negative electrode through the electrolyte and diaphragm, storing energy into the battery.
2) When discharging, the sodium ions move in the opposite direction to the charging process, releasing the energy in the battery to the power system.
3) As a battery operates, ions move between the anode and cathode through a substance called electrolyte.

Hybrid Batteries

A hybrid battery with high energy and high power density requires an improvement to the slow energy storage rate of battery-type anodes as well as the enhancement of the relatively low capacity of supercapacitor-type cathode materials. The assembled full cell, comprising the newly developed anode and cathode, forms a high-performance hybrid sodium-ion energy storage device. This device surpasses the energy density of commercial lithium-ion batteries and exhibits the characteristics of supercapacitors' power density. It is expected to be suitable for rapid charging applications ranging from electric vehicles to smart electronic devices and aerospace technologies. The hybrid sodium-ion energy storage device, capable of rapid charging and achieving an energy density of 247 Wh/kg and a power density of 34,748 W/kg (KAIST, 2024). Professor Jeung Ku Kang Korean KAIST scientists have developed a new sodium-ion battery that combines cathode and anode materials that has high energy density and rapid charging. They developed a new hybrid system by integrating anode materials typically used in batteries with cathodes suitable for supercapacitors, by utilizing two distinct metal-organic frameworks for the optimized synthesis of the hybrid batteries. This resulted in an anode material with improved kinetics through the inclusion of fine active materials in porous carbon derived from metal-organic frameworks. Additionally, a high-capacity cathode material was synthesized, and the combination of the cathode and anode materials allowed for the development of a sodium-ion storage system optimizing the balance and minimizing the disparities in energy storage rates between the electrodes (TOI 2024). This sodium-ion battery has an energy density that exceeds commercially available lithium-ion batteries along with the output density characteristics of a capacitor (Knight, 2024).

Researchers in the Netherlands at TU Delft Labs have improved sodium-ion battery performance by improving the battery's negative electrode, the anode, by making the anode from organic materials, thereby reducing dependence on outsourced materials. They also developed a "high-voltage, layered' cathode, improving the positive electrode, as well. The material appears to change its structure very gradually during charging and discharging, making it last even longer. It also contains no cobalt as is still common in (lithium-ion) cathodes (Kazmer, 2024),

Japanese researchers have developed a process that can lead to mass synthesis for sodium-containing sulfides electrolytes with high sodium ion conductivity, about 10 times higher than required for practical use, and glass electrolyte with high formability and reduction resistance, which is key to the practical use of all-solid-state sodium batteries. This process is useful for the production of almost all sodium-containing sulfide materials, including solid electrolytes and electrode active materials (Westenhaus, 2024B).

Thermal Batteries

Batteries enable the use of more renewable energy and reduce the need for costly grid upgrades. Storing energy is an important part of a low-carbon grid, and storing it as heat can be cheaper, safer and more convenient than storing it in traditional batteries. Thermal energy storage could boost wind and solar generation, and electrify industries which have moderate temperature requirements. A thermal battery is full of water, enough to fill three Olympic-sized pools, and contains all the heat that water holds. With a growing share of renewable electricity sources such as wind and solar, energy demand does not align with peak power production. Utilities smooth demand by charging more for power at peak times and far less when there is excess supply, such as overnight. Thermal batteries allow utilities or customers to move energy from one time of day, or even one time of year. Heat storage in thermal batteries allows buildings and manufacturers to buy power when it's cheapest. A thermal battery can be charged with hot water in the fall to help heat buildings on its district heating system through the winter. In the spring, the battery is charged with cold water, and uses the stored "cold" to help provide air conditioning. Thermal batteries can be used in manufacturing industries needing heat below 500 C and that are subject to volatile gas prices. In terms of space heating, thermal batteries make more sense in district energy systems that serve many buildings (Chung, 2024).

Evidence arguing for more use of thermal batteries includes The Energy Innovation Report by Axios, which found that thermal batteries could make industrial heating costs using electricity competitive with natural gas, while displacing 75 percent of fossil fuels burned for heat by U.S. industry. A 2020 report from the International Renewable Energy Agency (IRENA) expected the global market for thermal energy storage to triple by 2030, to 800 gigawatt hours. CSIRO, Australia's national science agency, estimates that thermal energy storage will be roughly a third cheaper than both lithium-ion batteries and pumped hydro for storage longer than four hours by 2050 (Chung, 2024).

Thermal Battery

1) Heat up a material, such as water or other substances that get much hotter, including graphite, sand or molten salt, up to 1,700 C.
2) Store it in a way that minimizes heat loss, such as in an insulated container, or underground.
3) Remove or transfer the heat to something like air or water for distribution when it's needed.

Dual Use, Heat or Electricity

1) The heat can be used to generate steam and turn turbines to generate electricity.
2) Used directly for space or water heating.

A vast thermal tank to store hot water is pictured in Berlin, Germany, on June 30, 2022. Power provider Vattenfall unveiled the new facility that turns solar and wind energy into heat, which can be stored in the tank and released into the German capital's grid as needed, smoothing out the fluctuating supply problem of renewables. (Michael Sohn/The Associated Press)

Electrostatic Capacitors

In modern electronics, electrostatic capacitors enable ultrafast charging and discharging, providing energy storage and power for devices ranging from smartphones, laptops, and routers to medical devices, automotive electronics and industrial equipment, as well as high-performance electronic devices, encompassing high-power electronics, high-frequency wireless communication systems, and integrated circuit chips. Advancements in operating efficiency of electrostatic capacitors are particularly crucial in sectors requiring robust power management solutions, such as electric vehicles and infrastructure development (Westenhaus, 2024A).

The ferroelectric materials used in capacitors have significant energy loss due to their material properties, making it difficult to provide high energy storage capability. U.S. scientists created artificial heterostructures made of freestanding 2D and 3D membranes to address energy loss in ferroelectric capacitors. The new material exhibits an energy density up to 19 times higher than commercially available capacitors while achieving an efficiency of over 90%. They controlled the relaxation time — an internal material property that describes how long it takes for charge to dissipate or decay – of ferroelectric capacitors using 2D materials. Dielectric relaxation time can be modulated or induced by a very small gap in the material structure, which enables the manipulation of dielectric material in such a way that it doesn’t polarize and lose charge capability. The 2D/3D/2D heterostructures can minimize energy loss while preserving the advantageous material properties of ferroelectric 3D materials. They sandwiched 2D and 3D materials in atomically thin layers with carefully engineered chemical and nonchemical bonds between each layer. A very thin 3D core is inserted between two outer 2D layers to create a stack only about 30 nanometers thick.30 nanometers is about one-tenth the size of an average virus particle. The 2D/3D/2D heterostructures are finely crafted to sit in the sweet spot between conductivity and nonconductivity where semiconducting materials have optimal electric properties for energy storage (Westenhaus, 2024A).

Long Duration Energy Storage Systems

Duration of dispatch	Storage technologies	Primary end-use
Short duration	Short Duration	Short Duration
0-4 hours	• Batteries	• Intra-day energy shifting (e.g., day to night)
	• Flywheels	• Frequency regulation
	• Some mechanical technologies	
Inter-day LDES	Inter-day LDES	Inter-day LDES
10–36 hours	• Most mechanical technologies	• Inter-day energy shifting
	• Some electrochemical technologies	(e.g., one point in a day to another point the next day)
Multi-day / week LDES	Multi-day/week LDES	
36–160 hours	• Many thermal technologies	Multi-day/week LDES
	• Many electrochemical technologies	• Resilience for extended shortfall of power

Seasonal Shifting	Seasonal Shifting	Seasonal Shifting
160+ hours	• Chemical storage (e.g., hydrogen)	• Shifting energy over months (e.g., summer to winter)

Chart: U.S. Energy Department, Pathways to Commercial Liftoff *https://liftoff.energy.gov/long-duration-energy-storage/#:~:text=LDES%20includes%20several%20technologies%20that,week%20LDES%2C%20and%20seasonal%20shifting*.

U.S. Biden Administration Energy Goals

1) 2050, Net Zero Emissions
2) 2035, 100% carbon-pollution free electricity

The U.S. wants to achieve liftoff of energy storage systems by 2030, with liftoff meaning a self-sustaining market where public capital is no longer needed and instead private capital can be deployed with a wide range of risk. To provide flexibility and reliability for the electric grid, due to increased use of intermittent renewable energy sources which cannot be turned on to meet peak demand the same way fossil-fuel sources can, battery storage options are needed. According to estimates, the U.S. grid will need 225-460 GW of LDES capacity for a net-zero economy by 2050, representing $330B in cumulative capital requirements. By 2050, net-zero pathways that deploy LDES result in $10-20B in annualized savings in operating costs and avoided capital expenditures compared to pathways that do not.[4]

3 Primary Market-Related Benefits of Batteries

1) Support and complement the expansion of variable renewables
    A) LDES can provide stability and flexibility to the grid as variable renewables expand
    B) LDES can reduce the cost of grid expansions by providing optionality and planning flexibility
2) Enhance grid resilience and reduce the need for new natural gas or coal capacity
    A) LDES can improve local and regional resiliency with increasing frequency of extreme weather events
    B) Available and cost-effective LDES reduces the need for more than 200GW of new natural gas capacity in a net-zero world
3) Diversify domestic energy storage supply chain
    A) A diversified set of storage technologies reduces the risk of net-zero goals being contingent upon lithium-ion manufacturing buildout, in addition to increasing the potential availability of lithium-ion for EVs

Improvements Needed

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[4] U.S. Energy Department, Pathways to Commercial Liftoff https://liftoff.energy.gov/long-duration-energy-storage/#:~:text=LDES%20includes%20several%20technologies%20that,week%20LDES%2C%20and%20seasonal%20shifting.

1) Technology performance and cost curves- LDES technology cost reduction of 45-55% and Round Trip Efficiency (RTE) improvement of 7-15% by 2030 to attract sustained investment.
2) Market and regulatory mechanisms- Market compensation of $50-75 per kilowatt-year via resource adequacy compensation or equivalent by 2030 to support a business case for investment.
3) Supply chain development and planning- 10-15 gigawatts of annual manufacturing deployment capacity by 2035 to handle the anticipated growth of LDES in the 2030s. Workforce will be the most significant risk to deployment, as most forms of LDES are highly engineering and construction intensive. Active planning such as expansion of on-the-job training and registered apprenticeship programs, project hybridization and modular project deployment can preclude gaps.

Technology Performance and Cost Curves

	Today (for best-in-class technology)	**2030 Target***
Intra-day LDES	$1,100–1,400 per kW 69% RTE	$650 per kW 75% RTE
Multi-day LDES	$1,900–2,500 per kW 45% RTE	$1,100 per kW 55–60% RTE

Market and Regulatory Mechanisms

Long-term market signals

Address stakeholder uncertainty and are particularly valuable for investors

- Carbon pricing
- GHG reduction targets
- Transmission expansion

Revenue mechanisms

Improve investors' risk-adjusted return on LDES

- Capacity markets
- Other market products for longer duration firm dispatchable power
- Long-term bilateral contracts
- 24/7 virtual PPAs

Analytics

Help to increase transparency and reduce uncertainty among stakeholders to enable long-term planning

- Decarbonization modeling tools
- 20-30 year integrated resource planning models
- Standardized model inputs

Direct technology support and enabling measures

Boost the market for LDES

- Direct grants and incentives
- PTCs
- Storage ITCs
- Loan guarantees

Stakeholder support

Ensure long-term viability of LDES

- Increased number of people employed by LDES
- Additional capital devoted to variable renewables or storage

Waste Disposal of Solar Panels[5]

The three primary options for PV module End-of-Life (EOL) disposal are: landfilling, recycling, and secondary use, with landfilling being the lowest cost handling option. As for module recycling, the process starts with mechanically removing the aluminum frames and then shearing off the junction box. For silicon recycling, the modules are then shred into small pieces, grinded into fine particles, and then the glass, polymers, interconnect ribbons, and cells are separated using eddy currents and sifting. Another silicon module recycling technique uses heat to remove the polymers from the glass, and then chemical treatments to separate the metals from the silicon. For Cadmium Telluride, CdTe, modules, after mechanical removal of the frame and junction box the commercial recycling process then proceeds to shred the laminate, grind it into small pieces in a hammermill, mechanical separate the glass and laminate pieces, and then immerse it in a series of chemical baths to recover the Cd and Te. In 2030, cumulative end-of-life PV waste in the United States is projected to be between 0.17 and 1 million tons, according to the International Renewable Energy Agency. This is compared to around 200 million tons of solid waste, excluding recycled and composted materials, generated in the United States each year. Estimates of annual PV module EOL volumes by 2050 is 12% of annual municipal electronic waste volumes in the United States. PV module materials are 99% non-hazardous and 95% of the materials are recyclable with current technologies. When recycling solar panels we want to research and develop safe and low impact EOL material handling tools, and to handle PV EOL volumes safely, responsibly, and economically, allowing for greater deployment and safe and socially responsible supply chains. The lifespan of PV

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[5] U.S. Department of Energy, (2022) Solar Energy Technologies Office Photovoltaics End-of-Life Action Plan

systems is currently at 25-35 years, but some consumers and plant operators may choose to upgrade their panels before the warranty period expires or to take advantage of technological improvements. Early end-of-life issues for solar panels are caused by weather damage, installation errors, and manufacturing serial defects.

Recycling Batteries

Lithium-ion batteries run everything from smartphones and laptops, to electric toothbrushes, and electric cars, and also are used to store wind and solar energy. In the future, as mineral deposits dry up, lithium-ion batteries will have to be recycled to recover the precious minerals used in their production, as the Earth does not contain enough accessible metal for us to mine forever. The batteries that we produce need to be safe, last a long time, and we need to recover the minerals when they reach their end of life. In order to meet our energy storage needs safely, we need to procure cheaper, more powerful batteries with fewer environmental costs. Large amounts of energy are created by mining metals to manufacture batteries, and this mining emits greenhouse gasses. A phone needs a different battery than an electric car, so not all lithium-ion batteries are the same, and thus we need recycling methods for each type of battery. Each cell in a lithium-ion battery contains numerous layers of metals, including lithium, nickel, cobalt, and manganese, and these metals layers do not always degrade in the same way. For example, some batteries can be crushed safely, but others cannot (Clean Technica, 2023).

Methods of Recycling Batteries

The first option wastes a lot of energy, and neither option recovers all the precious materials.

1) Melted down in a furnace
2) Dissolved in acid
3) Direct recycling- In this method, the battery is deconstructed without breaking any of the metals' chemical structures. This is a gentler process that could help recover more materials compared to the previous, more destructive recycling methods.

Biofuels

First-generation Biofuel Operations

-use food crops like corn, soy, and sugarcane as raw materials, or feedstocks
-because these feedstocks divert land and water away from food production, using them for biofuels is not ideal

Second-generation Biofuel Operations

-use non-edible plant biomass as feedstocks, such as wood residues from milling operations, sugarcane bagasse, or corn stover
-all of which are abundant low-cost byproducts of forestry and agricultural operations

U.S. researchers have designed a process that can better utilize both the lignin and sugars found in biomass by introducing a simple, renewable chemical to the pretreatment step to make next-generation biofuel production both cost-effective and carbon-neutral. Up to a billion tons per year of biomass could be made available for the manufacture of biofuels and bioproducts in the U.S. each year, capable of displacing 30% of our petroleum consumption, according to the

Department of Energy. The process they developed is known as CELF, which stands for co-solvent enhanced lignocellulosic fractionation, which is an innovative biomass pretreatment technology. CELF uses tetrahydrofuran or THF to supplement water and dilute acid during biomass pretreatment to improve overall efficiency and add lignin extraction capabilities, with the THF itself can be made from biomass sugars. Biorefinery operations must better utilize lignin, one of the main components of plant cell walls, to compete with petroleum. Lignin provides plants with greater structural integrity and resiliency from microbial attacks, though these natural properties of lignin also make it difficult to extract and utilize from the plant matter, known as biomass (Bernstein, 2024).

A CELF biorefinery can more fully utilize plant matter than earlier second-generation methods, so a heavier, denser feedstock like hardwood poplar, which is more expensive than less carbon-dense corn stover, can produce more fuel and chemicals. Using poplar in a CELF biorefinery, sustainable aviation fuel could be made at a break-even price as low as $3.15 per gallon of gasoline equivalent, with average cost for a gallon of jet fuel in the U.S. is $5.96 in 2024. There could be a rate of return of over 20% from the poplar CELF operation. This is because the U.S. government issues credits for biofuel production in the form of renewable identification number credits, a subsidy meant to bolster domestic biofuel production, and the tier of these credits issued for second-generation biofuels, the D3 tier, is typically traded at $1 per gallon or higher. Also, better lignin utilization through the CELF-THF method reduces the energy cost of pretreatment and helps isolate lignin, so you wouldn't have to burn it anymore, and thus can improve overall biorefinery economics while maintaining a low carbon footprint. In older biorefinery models, where biomass is cooked in water and acid, the lignin is mostly unusable for more than its heating value, and would burn the lignin to supplement heat and energy for these biorefineries because they could mostly only leverage the sugars in the biomass. The CELF biorefinery model also proposes to produce renewable chemicals to be used as building blocks for bioplastics and food and drink flavoring compounds. These chemicals take up some of the carbon in the plant biomass that would not get released back into the atmosphere as CO2 (Bernstein, 2024).

Domicile Wireless Electricity

Kambiz Moez, a University of Alberta engineering researcher, has developed a wireless light switch that could reduce the cost of wiring a house by as much as 50%. Wireless switches, consisting of a transmitter on the switch and a receiver near a light fixture or other appliance, have existed for a while, and can reduce the material and labor cost for wiring houses. However, most wireless switches until recently have required batteries to operate. The Alberta system utilizes switches that run without batteries, collecting energy from ambient sources such as radio frequency signals. In this new system, each floor would have one or two RF (radio frequency) power transmitters to power up all switches inside the house (McMaster, 2023).

The switch can also reduce energy consumption by accommodating sensors for temperature, humidity and occupancy. "Imagine heating a 3,000-square-foot house, but you're only using a room at any given time. If your house has wirelessly controlled vents, you can close the vents outside that room, or maybe a couple of bedrooms," says Moez. The seamlessly automated

Alberta system could also turn lights on and off as occupants move from room to room. "By enabling the wireless control of each section of homes, our solution prevents unnecessary use of energy, which in turn lowers energy bills and reduces carbon emissions," says Moez (McMaster, 2023). In a wireless switch, inside the switch there is a magnetic coil, and when the switch rocker is pressed it creates enough energy to send a radio signal to the receiver. The built-in receiver is wired to the light and stored in the light fixture. If the receiver is a plug-in module then it is simply plugged into an outlet and the device it controls is plugged into the receiver.

Solar Energy for Desalination

A) Need Access to Saltwater at the Beach
B) Attach different types of solar panels to the desalination device

We want to turn seawater from the oceans into fresh water that is suitable for people to drink. This is the purpose of solar desalination. Seawater contains dissolved salts at concentrations between 32 and 37.5 parts per thousand. That means that if you started with one kilogram, one liter, of seawater, and all of the water evaporated, there would be between 32 and 37.5 grams of salts left, in total dissolved solids. Seawater is not suitable for drinking nor for watering most plants. In the process of desalination, dissolved salts are removed from the seawater, making it pure enough for drinking or irrigation. Blood plasma, the fluid circulating in your body, contains less salt than seawater, around 9 grams of total dissolved solids in the blood plasma. When someone drinks seawater, their body loses water. This is because the high salt concentration of the seawater drives water out of the cells via an osmotic pressure gradient (Kinsman, 2007). Seawater is 220 times more salty than fresh water. The oceans are salty because rivers carry salt sediment from rocks into the oceans (Swenson, n.d.).

Parameters

1) How much water can the device produce?
2) Water purity- Is the water still salty at all?
3) What factors affect how effectively saltwater is turned into fresh water?
4) Heat transfer, Reflection of light, Absorption of light- Which colored bottom will result in a more efficient desalination device? White-colored bottom and a black-colored bottom. Light-colored objects reflect more light than dark-colored objects. Dark-colored objects absorb more of the light that hits it. In the process of heat transfer, light as a form of energy can be transferred to nearby objects, such as a body of water, in the form of heat.
5) Device with and without aluminum foil reflectors.
6) What are some factors that affect the rate of evaporation?

Measurements

1) Condensate yield, the amount of condensate collected; how efficient the devices are at heating the saltwater and producing desalinated water. Why does condensation form when water is heated up?
2) Conductivity of the saltwater and condensate; can be taken using a handheld meter. How well the condensed water had been purified of dissolved salt. This is because water

that contains dissolved salt can conduct electricity, and the more salt that is dissolved in the water, the higher the conductivity of the water.

Evaporation, Water vapor, Surface area

A large jug is used to hold the saltwater, which is laid on one side. This lets the saltwater cover a large area. Water molecules can only evaporate from the surface of water, so a body of water with a large surface area will have a greater rate of evaporation than a body of water with a smaller surface area. The top side of the jug is cut out and covered with plastic cling wrap. The cling wrap covering the opening provides a large surface area on which condensation can form. A quarter is used as a weight to make a low point at the center of the cling wrap. When the device is heated up in the sunlight, condensation forms on the cling wrap and flows down to this low point and drips into a funnel. The funnel is the cut-off top of a small water bottle, which has a flexible straw inserted into a hole cut in the cap. The other end of the straw passes through a small hole in the large jug, and then to a plastic cup. The plastic cup is covered with cling wrap using a rubber band to prevent evaporation (Kinsman, 2007).

Solar Energy for Water Electrolysis Hydrogen Production

Hydrogen is an alternative to fossil fuels, and is known as a sustainable energy vector. Grey and Blue hydrogen are produced through the methane steam reforming, a fossil fuel-based process that releases carbon dioxide (CO2) as a by-product, and are classified as “grey” (when CO2 is released into the atmosphere) or “blue” (when CO2 undergoes capture and geological storage). Green hydrogen depends on the energy efficiency of the setup (the electrolyzer) that splits water molecules into hydrogen and oxygen (Istituto Italiano, 2024). In 2022, global consumption of hydrogen was around 95 million tons, and was used to improve various fuel products, and especially to produce ammonia, which is needed for manufacturing agricultural fertilizers. Hydrogen production using gray hydrogen, made from natural gas or methane, and black hydrogen, made from coal, is responsible for around 2.5% of the annual global carbon dioxide emissions into the atmosphere. Green hydrogen is produced through electrolysis, which is the electrochemical decomposition of water into oxygen and hydrogen using energy from renewable sources such as wind and sun. Green hydrogen produced through electrolysis still is too expensive, including the need for expensive membranes, gaskets, and sealing components to separate the cathodic and anodic compartments (Technion-Israel, 2024). As of 2024, the world produces just 180 kilotonnes of electrolysis-based hydrogen per year, but could reach more than 14,000 kilotonnes by 2030 if all projects currently under construction become operational (Olano, 2024).

Alkaline Electrolyzer (Service, 2024)

-works a bit like a battery

1) Two electrodes are dropped in a chamber containing water and a liquid electrolyte that encourages the movement of ions
2) Applying an electric current to the negatively charged cathode splits the water into hydrogen molecules and negatively charged hydroxide ions
3) The hydroxide ions diffuse through the liquid to the positively charged anode, where they react to form oxygen and a smaller amount of water

4) The setup relies on a membrane between the two electrodes. It allows hydroxide ions to travel from the cathode to anode, but prevents the commingling of hydrogen and oxygen, which can combine explosively

Costs of Hydrogen Electrolysis (Service, 2024)

1) Renewable electricity that drives the process
2) Electrolyzer—and the membrane is one of its most expensive components, because it typically contains many specialized layers to house and protect the molecular filters

PUB Net-zero Emissions by 2045 Approach

1) Replacing fossil fuels with renewable solar energy
2) Investing in research and development to reduce the energy required in water-treatment processes
3) Capturing and removing carbon released into the atmosphere

In 2024, UCLA partnered with Singapore's national water agency to build the world's largest ocean-based carbon dioxide removal plant capable of removing 3,650 metric tons (8,046,873 lb) of the greenhouse gas per year while producing 105 metric tons (231,000 lb) of carbon-negative hydrogen. Agencies included in the project include: Singapore's national water agency, the Public Utilities Board (PUB), Singapore's National Research Foundation (NRF), and UCLA's Institute for Carbon Management (ICM). The World Bank suggests that average global carbon dioxide (CO2) emissions in 2020 were 4.3 metric tons (9,500 lb) per capita (McClure, 2024).

The project will be called Equatic-1 and uses electrolysis to produce hydrogen, passing an electrical current through seawater from adjacent desalination plants. Water is broken into its constituents, hydrogen and oxygen, through electrolysis chemical reactions, while atmospheric CO2 is dissolved and stored as solid calcium and magnesium-based materials for at least 10,000 years. The ocean has natural CO2-storing ability, and this process allows dissolved CO2 to be removed from the ocean while enabling it to absorb more of the greenhouse gas. Equatic-1's modular design will use selective anodes to produce oxygen while eliminating the unwanted chlorine byproduct created during seawater electrolysis. This opens both removes carbon dioxide at the gigaton scale and produces hydrogen. Equatic-1 will be built in two phases. Beginning in March, the first phase is designed to remove one metric ton (approximately 2,205 lb) of CO2 per day by late 2024. In early 2025, installing nine additional modules will complete phase two. With 10 modules in operation, it's expected that Equatic-1 will be able to remove 10 metric tons of CO2 per day from seawater and the atmosphere. The Singapore pilot plant was deemed successful after removing 0.1 metric ton (220 lb) of CO2 per day; Equatic-1 could remove 100 times more. The technology could also simultaneously produce nearly 300 kg (660 lb) of carbon-negative hydrogen daily (McClure, 2024).

Japanese researchers at the University of Tsukuba researchers have developed highly durable electrodes without precious minerals for green energy electrolysis hydrogen production from seawater, in a paper titled, "Durable high-entropy non-noble metal anodes for neutral seawater electrolysis" in the Chemical Engineering Journal. They used a multi-elemental alloy electrode composed of nine non-noble metal elements, and conducted an accelerated degradation test, consisting of turning the power supply on and off, which mainly caused degradation during the operation of the water electrolysis system, suggests sustained anode performances for over a decade when powered by solar energy. This multi-element anode alloy requires higher voltages than that of the precious metal, such as iridium oxide to offer direct seawater electrolysis without using fresh water (Westenhaus, 2024D).

Renewable energy sources can be used to perform water electrolysis as a clean method for hydrogen production. Since the water electrolysis method for hydrogen production relies on freshwater, thereby limiting the regions available with water resources required for water electrolysis, a new technology for water electrolysis that can directly harness the abundant supply of seawater is needed. Seawater electrolysis utilizes an anode reaction to generate oxygen from water, chlorine gas, and hypochlorous acid from chloride ions. The anode electrodes are precious metal electrodes, such as platinum oxide, ruthenium oxide, and iridium oxide, which are unaffected by chlorine. However, precious metals as electrodes for seawater electrolysis technology have a high cost, although non-noble metals, which are highly reactive with chloride ions, cannot be employed for durable anodes (Westenhaus, 2024D).

Italian researchers have developed a method utilizing small ruthenium particles, a new family of electrocatalysts, in conjunction with a solar-powered electrolysis system for water electrolysis to produce green hydrogen more efficiently and cheaply. They found a greater efficiency than other methods in the conversion of electrical energy (the energy bias exploited to split water molecules) into the chemical energy stored in the hydrogen molecules that are produced. Using nanoparticles of ruthenium, a noble metal that is similar to platinum in its chemical behavior but far cheaper, the ruthenium nanoparticles serve as the active phase of the electrolyzer's cathode, leading to an increased efficiency of the overall electrolyzer (Istituto Italiano, 2024).

A) Theoretical simulations to understand the catalytic behavior of ruthenium nanoparticles at the molecular level; the mechanism of water splitting on their surfaces
B) Electro-chemical analyses and tests under industrially-significant conditions to assess the catalytic activity of materials

Using a precious metal such as ruthenium results in an initial investment that is slightly greater than what would be needed for a standard electrolyzer, to improve the efficiency of ruthenium-based cathodes for alkaline electrolyzers. Ruthenium is a precious metal that is obtained as a by-product of platinum extraction (30 tonnes per year, as compared to the annual production of 200 tonnes of platinum) but at a lower cost (18.5 dollars per gram as opposed to 30 dollars for platinum). The Italian researchers used 40 mg of ruthenium per kilowatt, in stark contrast with the extensive use of platinum (up to 1 gram per kilowatt) and iridium (between 1 and 2.5 grams per kilowatt, with iridium price being around 150 dollars per gram) that characterize proton-exchange membrane electrolyzers (Istituto Italiano, 2024).

2019 E-TAC Electrolysis

E-TAC electrolysis, developed by Israeli Technion researchers, doesn't require a membrane and sealing to separate the two parts of the cell, since the hydrogen and the oxygen are produced at different stages of the process, unlike in regular electrolysis where they are created simultaneously (Technion-Israel, 2024). This model does away with the membrane by "decoupling" the electrolysis and separating the hydrogen and oxygen production in space or time. They charged a nickel-based electrode like a battery during the hydrogen production step, and when they moved that electrode to a second chamber, it produced oxygen as it discharged (Service, 2024).

Challenges 2019 Design

1) Moving the electrode between steps means the reactor can't operate continuously, likely making it expensive to scale up.
2) The electrolyte used in the oxygen generation step must be hot to speed the reaction, requiring the use of expensive materials and insulation to prevent heat loss.

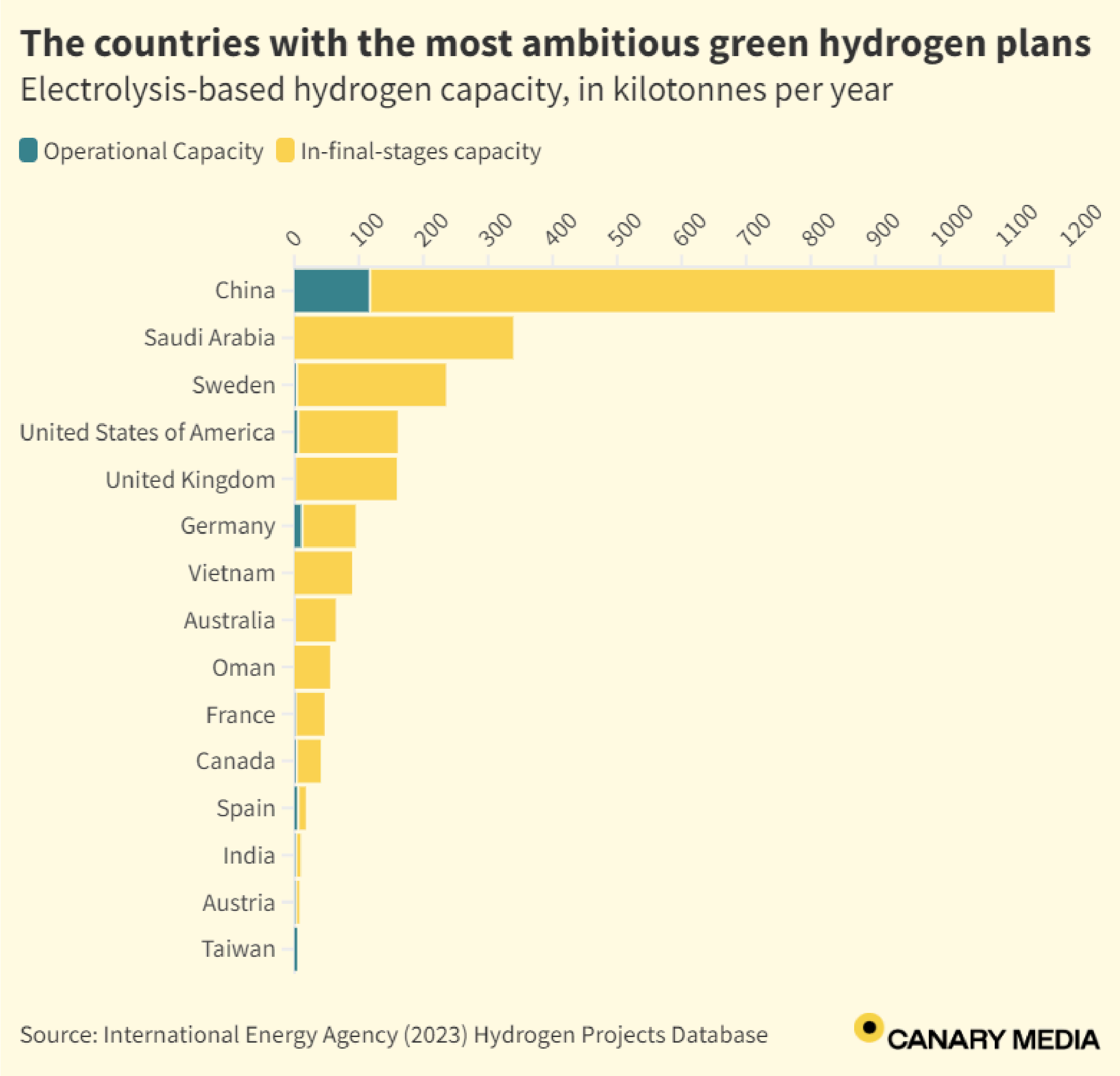
2024 Technion Electrolysis

Unlike the E-TAC process where hydrogen and oxygen are produced in the same cell but at different stages, this is a new process whereby hydrogen and oxygen are produced simultaneously in two separate cells in a continuous process without any temperature changes. The solid electrode where the oxygen is produced in the E-TAC technique is replaced with NaBr aqueous electrolyte in water. This NaBr replacement allows for a continuous process, as opposed to a batch process with E-TAC, and removes the need to swing cold and hot electrolytes alternately through the cell. The bromide anions in the electrolyte are oxidized to bromate while producing hydrogen in a cathode, and they then flow with the aqueous electrolyte to a different cell, where they are turned back into their original state while at the same time producing oxygen. Moreover, the oxygen is produced in the aqueous electrolyte and not in the solid electrode as in E-TAC, and it is therefore not dependent on the rate and capacity limitations typical of those types of electrodes, such as chargeable batteries (Technion-Israel, 2024). In the 2024 Design, the decoupled electrolyzer was designed so that hydrogen production didn't charge the anode, but instead altered molecules in the liquid electrolyte. During hydrogen production at the anode, bromide ions in the electrolyte are converted to bromate, and that bromate-containing electrolyte is pumped into a second chamber, which has a catalyst that causes the bromate to decompose back into bromide and oxygen in a reaction that works at room temperatures (Service, 2024).

Challenges to 2024 Design

1) The efficiency wasn't as high as a typical alkaline electrolyzer, though they were able to keep the hydrogen and oxygen separate without a membrane, which could reduce the cost of large-scale hydrogen production.
2) To prevent bromate from reacting at the anode before it can be pumped to the second chamber, the team had to coat the anode with a material that allows hydrogen to escape but blocks bromate from reaching the anode. And that coating required adding hexavalent chromium, a powerful carcinogen, to the solution, raising concerns about toxic leaks.

3) The electrodes in the device use either platinum or ruthenium, which are expensive and rare metals.



The countries with the most ambitious green hydrogen plans

Electrolysis-based hydrogen capacity, in kilotonnes per year

Source: International Energy Agency (2023) Hydrogen Projects Database

Source: Olano, Maria (2024) Canary Media. Chart: Which countries are leading the green hydrogen race? https://www.canarymedia.com/articles/hydrogen/chart-which-countries-are-leading-the-green-hydrogen-race

Hydrogen Energy, Liquified and Gaseous

Two atom dihydrogen (H2) can be used in vehicles and electric power plants. Hydrogen is an energy carrier that can be used to store, move, and deliver energy produced from other sources.[6] Hydrogen is a clean fuel that produces water and heat when consumed in a fuel cell. Hydrogen, by means of electrolysis, provides a sustainable solution for energy storage, transportation fuel and industrial applications. Electrolysis-produced hydrogen could aid in the storage of renewable energy sources, making renewable energy sources more dispatchable and allowing for long-duration energy storage. For transportation, hydrogen fuel cell technology provides an alternative to gas or electric that offers zero emissions, while maintaining the range and refueling time comparable to gas-powered vehicles. Hydrogen energy generation can provide cost-effective on-site production for industrial uses (Malayil, 2023).

Liquid hydrogen is the key to fuel cell efficiency. I envisage a future where green hydrogen powers our vehicles, industrial applications, and energy storage needs. Existing gas and oil pipelines could be repurposed to carry hydrogen, and our gas stations could be refitted for hydrogen fuel over gasoline. I think that hydrogen fuel is more promising than electric vehicles, because of refueling and recharging times. It takes too long to charge an electric vehicle, and unless you have a garage you cannot charge at home. A major challenge and the topic of this thesis is how do we create enough renewable power to power the green hydrogen creation process. We can use solar panels, wind turbines, and nuclear energy to power our power plants, and also for industrial applications including green hydrogen production. Solar collectors for industrial power sources have potential to power industry and factories, and we can also use green hydrogen to create ammonia for fertilizer, with nitrogen taken from the air.

Manganese Catalyst with Lower Iridium for Hydrogen Electrolysis

Hydrogen electrolysis production in a proton exchange membrane (PEM) electrolyzer requires a catalyst to break the bonds of water and free the hydrogen, and the most widely used catalyst is iridium. However, iridium is a rare earth transition metal, very expensive to find and mine, and consequently scaling up global hydrogen production to the terawatt scale is estimated to require 40 years' worth of iridium, according to Shuang Kong of Japan RIKEN. Japanese RIKEN researchers have been experimenting with replacing 95% of iridium with manganese oxide as the catalyst, a common earth metal. The Japanese researchers spread individual iridium atoms on a piece of manganese oxide, preventing them from clumping together (McFadden, 2024).

The manganese catalyst allowed hydrogen production continuously for over 3000 hours (about four months) at 82% efficiency without any degradation. Ailong Li suggests that the unexpected interaction between manganese oxide and iridium was critical, with the iridium resulting from this interaction being in the rare and highly active +6 oxidation state. To achieve sustainable green hydrogen production, we must complement the rare metals currently used with common metal-based electrolyzers (McFadden, 2024).

Solid Oxide Electrolysis Cell (SOEC)

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[6] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Hydrogen and Fuel Cell Technologies Office, HYdrogen Fuel Basics, https://www.energy.gov/eere/fuelcells/hydrogen-fuel-basics

In Korea, researchers at the Korea Institute of Energy Research (KIER) developed an 8 kW solid oxide electrolysis cell (SOEC) that can reportedly produce 5.7 kg of hydrogen per day to provide stable operation for 2,500 h. The SOEC stack was constructed by layering ceramic cells, separator plates, and sealing materials. The separator plate was created using a press forming method that reduces production costs and time. Channels were created using this SOEC technique that enables a proper flow of hydrogen and oxygen in the system. The group maximized the contact area between the cell and the separator plate, which allows for more uniform performance, and sealed the stacked components via brazing technology, which ensures that the stack can minimize hydrogen leakage even in the face of thermal shock or rapid temperature changes, thus maintaining stable performance (Bellini, 2024A).

This a solid oxide electrolysis cell stack that uses a special kind of separator plate to ensure proper flow of hydrogen and oxygen after water splitting. In a SOEC system, a solid oxide, or ceramic, is used to produce hydrogen and oxygen. Water supplied at the cathode is used to separate hydrogen from water in an external separation unit, with the hydroxide ions flowing through an aqueous electrolyte to the anode to generate oxygen. The Korean researchers said that, “The SOEC technology, which electrolyzes high-temperature steam into hydrogen and oxygen, is considered a high-efficiency hydrogen production technology that can reduce electricity consumption by more than 25% compared to other electrolysis methods when applied to places with a large demand for hydrogen and/or a large steam supply, such as nuclear power plants, steel mills, petrochemical plants, and ammonia manufacturing plants.” (Bellini, 2024A)

Hydrogen storage options

1) Gaseous, leaks and is combustible
2) Liquid, low temperatures
3) Hydrogen boride sheets, low conversion rates

Stages of hydrogen conversion

1) Geologic hydrogen rocks
2) Fossil fuel hydrogen
3) Green hydrogen electrolysis
4) Gold hydrogen deposits

Energy Storage Options

1) Electrochemical Batteries, Lithium and Sodium
2) Thermal Batteries, Heated Water
3) Mechanical Storage, Hydroelectric Dams
4) Chemical Storage, Ethanol and Hydrogen

1) Hydrogen engines are less efficient than electric vehicles and lose more energy in the conversion process.
2) Hydrogen fuel is more combustible than gasoline.

Processes to Produce Hydrogen Fuel

1) Natural gas reforming, steam-methane reforming; Thermal process- Steam reforming is a high-temperature thermal process for hydrogen production in which steam reacts with a hydrocarbon fuel to produce hydrogen. Hydrocarbon fuels which can be reformed to produce hydrogen include: natural gas, diesel, renewable liquid fuels, gasified coal, or gasified biomass. As of 2023, about 95% of all hydrogen is produced from steam reforming of natural gas.
2) Electrolysis- Electrolysis is a process in which water is separated into oxygen and hydrogen. An electrolyzer, which mirrors a fuel cell in reverse, is where electrolysis processes take place. In the electrolyzer, hydrogen is created from water molecules, instead of using the energy of a hydrogen molecule, like a fuel cell does.
3) Solar-driven, photolytic process- Light is used as the agent for hydrogen production in solar-driven processes. Solar-driven processes include: photobiological, photoelectrochemical, and solar thermochemical. In photobiological processes, the natural photosynthetic activity of bacteria and green algae is used to produce hydrogen. In photoelectrochemical processes, specialized semiconductors are used to separate water into hydrogen and oxygen. In solar thermochemical hydrogen production, concentrated solar power is used to drive water splitting reactions often along with other species such as metal oxides.
4) Biological processes- Microbes such as bacteria and microalgae are used to produce hydrogen through biological reactions in biological processes. Microbial biomass conversion is a process in which the microbes break down organic matter like biomass or wastewater to produce hydrogen, while photobiological processes for the energy source the microbes use sunlight.
5) Thermochemical processes- Convert biomass into gas or liquids and separate the hydrogen

Hydrogen Storage Options

1) Gas- Storage of hydrogen as a gas typically requires high-pressure tanks (350–700 bar [5,000–10,000 psi] tank pressure).
2) Liquid- Storage of hydrogen as a liquid requires cryogenic temperatures because the boiling point of hydrogen at one atmosphere pressure is −252.8°C.
3) Adsorption- on the surfaces of solids
4) Absorption- within solids

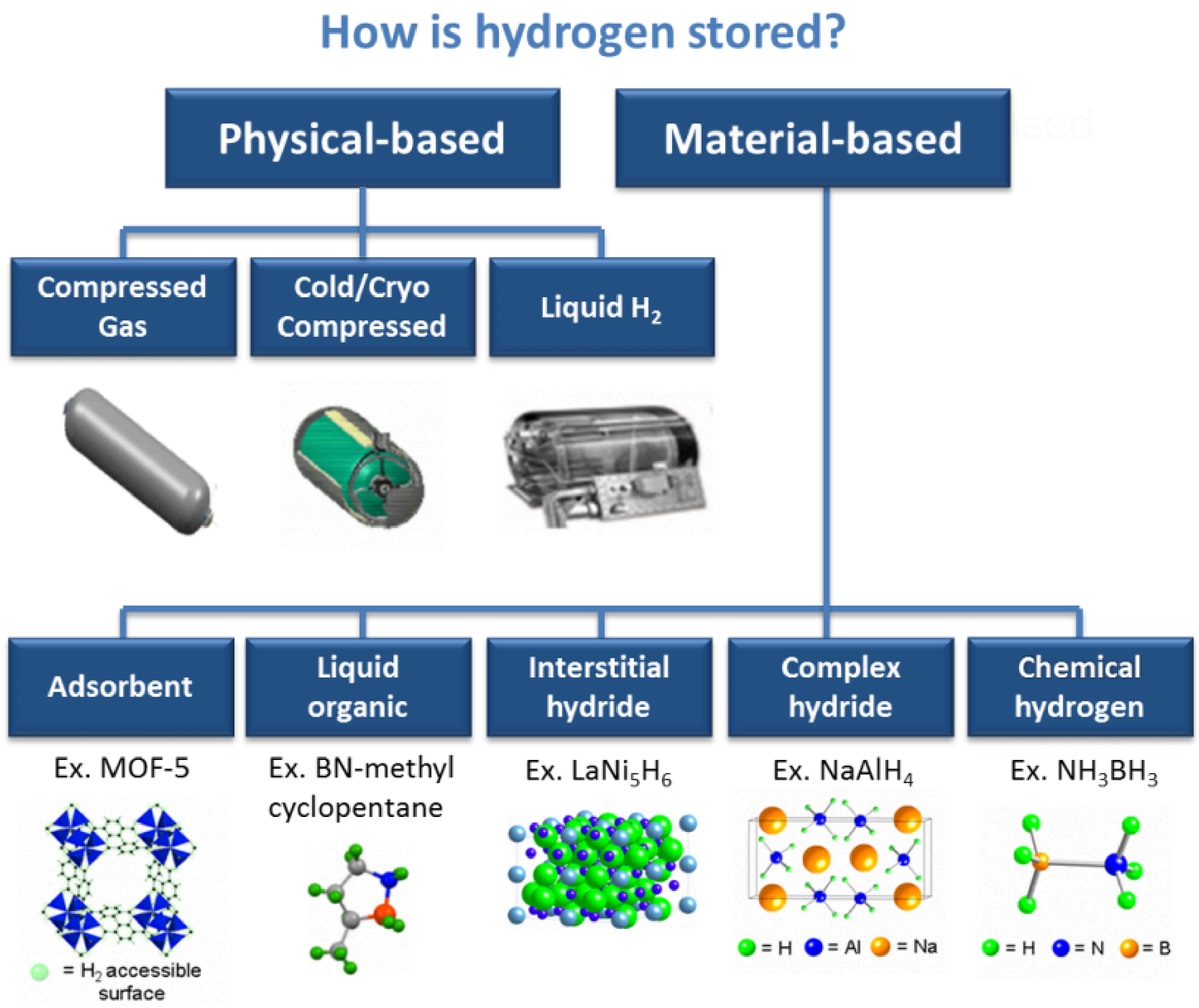
According to the U.S. Department of Energy, hydrogen has the highest energy per mass of any fuel; however, its low ambient temperature density results in a low energy per unit volume, therefore requiring the development of advanced storage methods that have potential for higher energy density. On a mass basis, hydrogen has nearly three times the energy content of gasoline—120 MJ/kg for hydrogen versus 44 MJ/kg for gasoline. On a volume basis, however, the situation is reversed; liquid hydrogen has a density of 8 MJ/L whereas gasoline has a density of 32 MJ/L, as shown in the figure comparing energy densities of fuels based on lower heating values. Onboard hydrogen storage capacities of 5–13 kg hydrogen will be required to meet the driving range for the full range of light-duty vehicle platforms.

To overcome these challenges Hydrogen and Fuel Cell Technologies Office (HFTO) is pursuing two strategic pathways, targeting both near-term and long-term solutions. The near-term pathway focuses on compressed gas storage, using advanced pressure vessels made of fiber reinforced composites that are capable of reaching 700 bar pressure, with a major emphasis on system cost reduction. The long-term pathway focuses on both (1) cold or cryo-compressed hydrogen storage, where increased hydrogen density and insulated pressure vessels may allow for DOE targets to be met and (2) materials-based hydrogen storage technologies, including sorbents, chemical hydrogen storage materials, and metal hydrides, with properties having potential to meet DOE hydrogen storage targets.

Hydrogen Embrittlement

Hydrogen embrittlement is a major obstacle to the transition to a global hydrogen economy, and to develop large-scale transport and storage solutions for the hydrogen age, to be able to effectively produce, transport, store and use hydrogen on a large-scale, we need to determine why stored hydrogen causes steels to become brittle and crack. When hydrogen embrittlement occurs, hydrogen causes high strength materials like steel to become brittle and crack, which prevents hydrogen from being effectively stored and transported at high pressures. As the smallest atom and molecule, hydrogen is insidious, and it seeps into materials, then cracks and breaks them. Deloitte estimates the clean hydrogen market could reach USD$1.4 trillion by 2050 (U Sydney, 2024).

Ceramic carbides are added to steels to increase their durability and strength, and in this experiment, molybdenum was added to the steel, combined with other elements to form the carbide. By adding the chemical element molybdenum to steel reinforced with metal carbides, its ability to trap hydrogen was greatly increased, according to the Australian researchers. An advanced microscopy technique developed at the University of Sydney, known as cryogenic atom probe tomography, was used to allow for direct observation of hydrogen distribution in materials, in which the researchers saw the trapped hydrogen atoms were at the core of the carbide sites, suggesting the addition of molybdenum helps trap hydrogen. Conversely, a benchmark titanium carbide steel did not show the same hydrogen trapping mechanism. The addition of molybdenum, only 0.2% of the total steel, helped boost the presence of carbon vacancies, a defect in carbides that can effectively capture hydrogen. The researchers also believe niobium and vanadium may also have a similar effect as molybdenum on steels (U Sydney, 2024).



Source: US Department of Energy, Office of Energy Efficiency and Renewable Energy, Hydrogen and Fuel Cells Technologies Office, Hydrogen Storage. https://www.energy.gov/eere/fuelcells/hydrogen-storage#:~:text=Hydrogen%20can%20be%20stored%20physically,pressure%20is%20%E2%88%92252.8%C2%B0C

Japanese scientists developed a method to release hydrogen from hydrogen boride sheets electrochemically using an electrical current, a safe and lightweight hydrogen carrier with low energy consumption. which is more efficient than traditional methods requiring high temperatures or UV light. They demonstrated that dispersing these sheets in an organic solvent and applying a small voltage is enough to release all the stored hydrogen efficiently. The Faradaic efficiency of this process, which measures how much electrical energy is converted into chemical energy, was over 90%. Traditionally, getting the hydrogen out of the sheets is the difficult part, as heating at high temperatures or strong ultraviolet (UV) illumination is required to release H2 from HB sheets. But both approaches have inherent disadvantages, such as high energy consumption or incomplete H2 release. The Japanese researchers used electrochemical release to separate the hydrogen from the boride sheets. In consideration of the mechanism of

UV-induced H2 release from HB sheets, the team speculated that electron injection from a cathode electrode into HB nanosheets by an electric power supply could be a superior way to release H2 compared to UV irradiation or heating. Based on this theory, the researchers dispersed HB sheets into acetonitrile – an organic solvent – and applied a controlled voltage to the dispersion. The experiments revealed that nearly all of the electrons injected into the electrochemical system were used to convert H+ ions from the HB sheets into H2 molecules (Westenhaus, 2024C).

Researchers in the United States are looking at ways to produce geologic hydrogen, by exploring a suite of natural catalysts to help produce hydrogen gas from iron-rich rocks without emitting carbon dioxide. A $1.7 million grant from the Department of Energy was issued to the UT Austin and the University of Wyoming to explore the feasibility of this process on different rock types across the United States. Catalyst-enhanced production of hydrogen from iron-rich rocks has the potential to significantly increase hydrogen production globally. A natural geologic process known as “serpentinization” is the catalyst, where iron-rich rocks release hydrogen as a byproduct of chemical reactions, as serpentinization usually occurs at high temperatures. The team is using natural catalysts including nickel and other platinum group elements, to stimulate hydrogen production at lower temperatures and at depths easily accessible by today’s technology where iron-rich rocks are found throughout the world. The goal is to generate larger volumes of hydrogen from these iron-rich rocks by driving reactions that would take several million years to happen in nature. The team will investigate using the catalysts on basalts from the Midcontinent Rift in Iowa, banded iron formations in Wyoming and ultramafic rocks in the Midwest (UT Austin, 2024).

Hydrogen Fuel Cells[7]

1) Proton exchange membrane- Polymer electrolyte membrane (PEM) fuel cells, or proton exchange membrane fuel cells, use for an electrolyte a proton-conducting polymer membrane, with hydrogen as the fuel. PEM cells can quickly vary their output to meet changing power demands, and operate at low temperatures. PEM fuel cells are used for automobiles, but they can also be used for stationary power production. Due to their low operating temperature, however, PEMs cannot directly use hydrocarbon fuels, such as natural gas, liquefied natural gas, or ethanol, so these fuels must be converted to hydrogen in a fuel reformer to be able to be used by a PEM fuel cell.
2) Alkaline membrane- Alkaline electrolytes such as potassium hydroxide or alkaline membranes that conduct hydroxide ions rather than protons are used in alkaline fuel cells. These fuel cells have been used by NASA for space missions, and for portable power.
3) Direct methanol fuel cells- Both the direct-methanol fuel cell (DMFC) and the PEM cell use a proton conducting polymer membrane as an electrolyte. DMFCs eliminate the need for a fuel reformer, however, by using methanol directly on the anode. Laptop

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[7] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Hydrogen and Fuel Cell Technologies Office, Fuel Cell Basics, https://www.energy.gov/eere/fuelcells/fuel-cell-basics#:~:text=Polymer%20electrolyte%20membrane%20(PEM)%20fuel,to%20meet%20shifting%20power%20demands.

computers and battery rechargers, portable electronic devices, can be powered with DMFCs, because methanol provides a higher energy density than hydrogen. .

4) Phosphoric acid fuel cells- Phosphoric acid fuel cells operate at about 200°C in a porous matrix holding a phosphoric acid electrolyte that conducts protons. They can be used in modules of 400 kW or greater and are being used for stationary power production in hotels, hospitals, grocery stores, and office buildings, where waste heat can also be used. By being immobilized in polymer membranes, phosphoric acid fuel cells membranes can be used for stationary power applications.
5) Molten carbonate fuel cells- Molten carbonate fuel cells utilize a porous matrix with a molten carbonate salt that conducts carbonate ions as their electrolyte, and are used in medium-to-large-scale stationary applications, where their high efficiency produces net energy savings. Their high-temperature operation, approximately 600°C, enables them to internally reform fuels such as natural gas and biogas.
6) Solid oxide fuel cells- Solid oxide fuel cells use as a solid electrolyte a thin layer of ceramic that conducts oxide ions, and can be used in stationary power applications, as well as in auxiliary power devices for heavy-duty trucks. Operating at 700°C–1,000°C with zirconia-based electrolytes, and as low as 500°C with ceria-based electrolytes, these fuel cells can internally reform natural gas and biogas, and can be combined with a gas turbine to produce electrical efficiencies as high as 75%.
7) Combined heat and power fuel cells- Fuel cells produce heat in addition to electricity. . Combined heat and power fuel cells are of interest for powering houses and buildings, including hot water and space heating, where total efficiency as high as 90% is achievable.
8) Regenerative or reversible fuel cells- This fuel cell produces electricity from hydrogen and oxygen, but can also be reversed and powered with electricity to produce hydrogen and oxygen. This fuel cell could provide storage of excess energy produced by intermittent renewable energy sources, such as wind and solar power stations.

AVL Racetech, an Austrian motorsport engineering firm, has developed the H2-ICE engine, a hydrogen powertrain that combines the characteristics of ICE and EV technologies. It is a 2.0-liter turbocharged engine that produces 410 horsepower (hp) and reaches peak power at 6,5000 rpm. With its use of water injections, it infiltrates more water with the intake air. This advanced technology creates optimal performance and is a great step forward in creating cleaner internal combustion engines (The Moment KB, 2024).

Catalysts[8]

Key to improving the operating abilities of hydrogen fuel cells is isolating and optimizing the catalysts and polymer electrolytes. Catalyst research focuses on developing and optimizing advanced electrocatalysts and new synthesis methods, including extended-surface catalysts with reduced precious-metal loading and improved performance, durability, and activity compared to standard catalytic materials. Fuel cells and electrolyzer catalysts act differently under acidic and alkaline conditions. The focus of this research is on thrifting platinum, iridium,

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[8] NREL, National Renewable Energy Laboratory, https://www.nrel.gov/hydrogen/fuel-cells.html

and their alloys in acidic-based systems, and thrifting silver, cobalt, nickel, and their oxides/alloys in alkaline-based systems.

Polymer Electrolytes

Perfluorinated alkaline membranes can be analyzed in terms of new chemistries to enable higher-temperature and higher-current-density operation. Alkaline membrane fuel cells enable the use of non-precious-metal catalysts. However, alkaline membranes are vulnerable to ambient carbon dioxide conditions, although this vulnerability decreases at higher operating temperatures. Proton exchange membranes with tethered heteropolyacid functionality can allow higher-temperature, lower-humidity operation. The stability of covalently tetherable cations in proton exchange membranes is also being researched.

Fuel Cell Electric Vehicles (FCEL)[9]

Hydrogen fuel cells generate electricity through an electrochemical reaction instead of combustion. FCEVs produce electricity using a fuel cell powered by hydrogen, rather than drawing electricity from only a battery, like conventional electric vehicles. The power of the vehicle is determined by the size of the electric motor(s) that receives electric power from the appropriately sized fuel cell and battery combination. FCEVs use a propulsion system where energy stored as hydrogen is converted to electricity by the fuel cell, which is similar to that of electric vehicles. These vehicles also produce no harmful tailpipe emissions, like electric vehicles, and unlike internal combustion engine vehicles; they only emit water vapor and warm air. FCEVs utilize a tank on the vehicle which is fueled with pure hydrogen gas or liquified hydrogen. These hydrogen vehicles are similar to conventional internal combustion engine vehicles, in that they have a driving range of more than 300 miles and can fuel in about 5 minutes. FCEVs are equipped with regenerative braking systems that capture the energy lost during braking and store it in a battery. This braking energy recapture technology provides extra power during short acceleration events, and smooths out the power delivered from the fuel cell with the option to idle or turn off the fuel cell during low power needs. In hydrogen vehicles, the amount of energy stored onboard is determined by the size of the hydrogen fuel tank. Conversely, in all-electric vehicles, the amount of power and energy available are both closely related to the battery's size. Hydrogen is considered an alternative fuel under the Energy Policy Act of 1992 and qualifies for alternative fuel vehicle tax credits.

The polymer electrolyte membrane (PEM) fuel cell is the most common type of fuel cell for hydrogen vehicle applications. In a PEM fuel cell, the electrolyte membrane is located between the positive electrode (cathode) and the negative electrode (anode). There are bipolar plates on either side of the cell that serve as current collectors and help distribute gasses. The hydrogen conversion process begins when hydrogen fuel is introduced to the anode, and oxygen from the air is introduced to the cathode. This means that an oxidation occurs at the anode, while a reduction occurs at the cathode, with the two reactions connected by a charged species that migrates through the electrolyte and electrons that flow through the external circuit. Next, an electrochemical reaction in the fuel cell, a catalyst, breaks the hydrogen molecules apart into

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[9] U.S. Department of Energy, Alternative Fuels Data Center, https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work

protons and electrons, where the protons travel in different paths to the cathode through the membrane. Traveling through an external circuit, the electrons perform work, creating a flow of electricity, including providing power to the electric car, and then recombine with the protons on the cathode side where the protons, electrons, and oxygen molecules combine to form wastewater and heat.

Different types of fuel cells use different electrolytes and serve different application needs, with the charged species traveling through the electrolyte and the fuel being different, though the basic functions remain the same. A fuel cell stack may contain anywhere from a few to hundreds of individual fuel cells layered together, with this scalability making hydrogen fuel cells ideal for a wide variety of applications, such as stationary power stations, portable devices, and transportation. Fuel cells work like batteries, and they produce electricity and heat as long as fuel is supplied, but they do not run down or need recharging like a battery does.

Liquid Hydrogen, LH2[10]

GENH2 writes that creating systems that produce, liquefy, store, and use hydrogen is critical to the renewable energy economy. This view may be debated, as to the overall need for the hydrogen economy, but what is true is that hydrogen has potential for use as a fuel source. Hydrogen can be used as an energy carrier, and this includes hydrogen fuel cells. Hydrogen fuel cells can be used for providing power, including transportation, industrial/commercial/ residential buildings, and long-term energy storage.

Liquid hydrogen (LH2) is a higher purity for the hydrogen fuel, which allows the fuel cells to operate at higher efficiency and can convert the chemical energy in the hydrogen directly to electrical energy with efficiencies capable of exceeding 60%, according to GENH2. The liquefaction of the hydrogen as the energy carrier supply used for fuel cells maximizes the amount of fuel that can be stored, by increasing the energy density and purity of hydrogen. Machines powered by hydrogen fuel cells can achieve longer operational periods between refueling due to the increased density and storage process of liquified hydrogen.

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[10] GENH2, LIQUID HYDROGEN IS THE KEY TO FUEL CELL EFFICIENCY, https://genh2hydrogen.com/blog/liquid-hydrogen-the-key-to-fuel-cell/#:~:text=Fuel%20cell%20systems%20are%20a,fuel%20cell%20is%20higher%20purity.

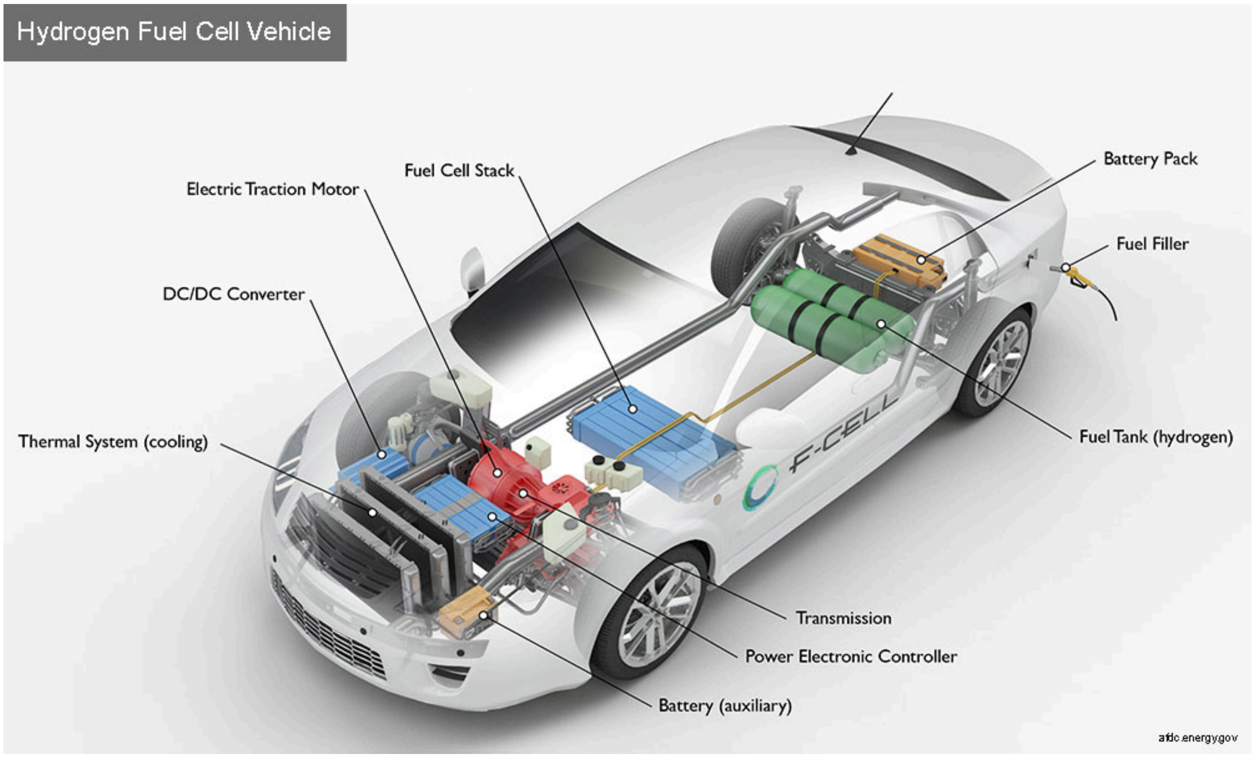


Image: U.S. Department of Energy, Alternative Fuels Data Center, https://afdc.energy.gov/vehicles/how-do-fuel-cell-electric-cars-work

Electric Battery Power Train Components

-There are also sensors and computerized controls and the like, but very few moving parts and very little that requires much maintenance (Barnard, 2024).

1) Batteries
2) Electricity charging system with no moving parts except the flap over the plug
3) Power management unit to move electricity across wires to the motor
4) Motor

Hydrogen Fuel Cell Vehicle, Battery Hydrogen Hybrid Vehicle

-A heavy duty fuel cell vehicle like a freight truck or transit bus is a battery electric vehicle with added fuel cell drive train components (Barnard, 2024).

1) Adds a 700 atmosphere hydrogen tank or an even more sophisticated liquid hydrogen tank with pressure sensor and relief systems
2) Hydrogen fuel movement system which has to deal with very large pressure changes in the case of the pressurized tanks or very large volume and hence pressure changes as liquid hydrogen is warmed to gaseous form
3) Very large thermal management challenges and hence thermal management sensors, actuators and components in both cases
4) Expensive and life-limited fuel cell which requires pure hydrogen and and clean air
5) Air intake and filtering system as a result and an exhaust system for moving the resultant water from the fuel cell out of the vehicle without freezing hence a heating solution

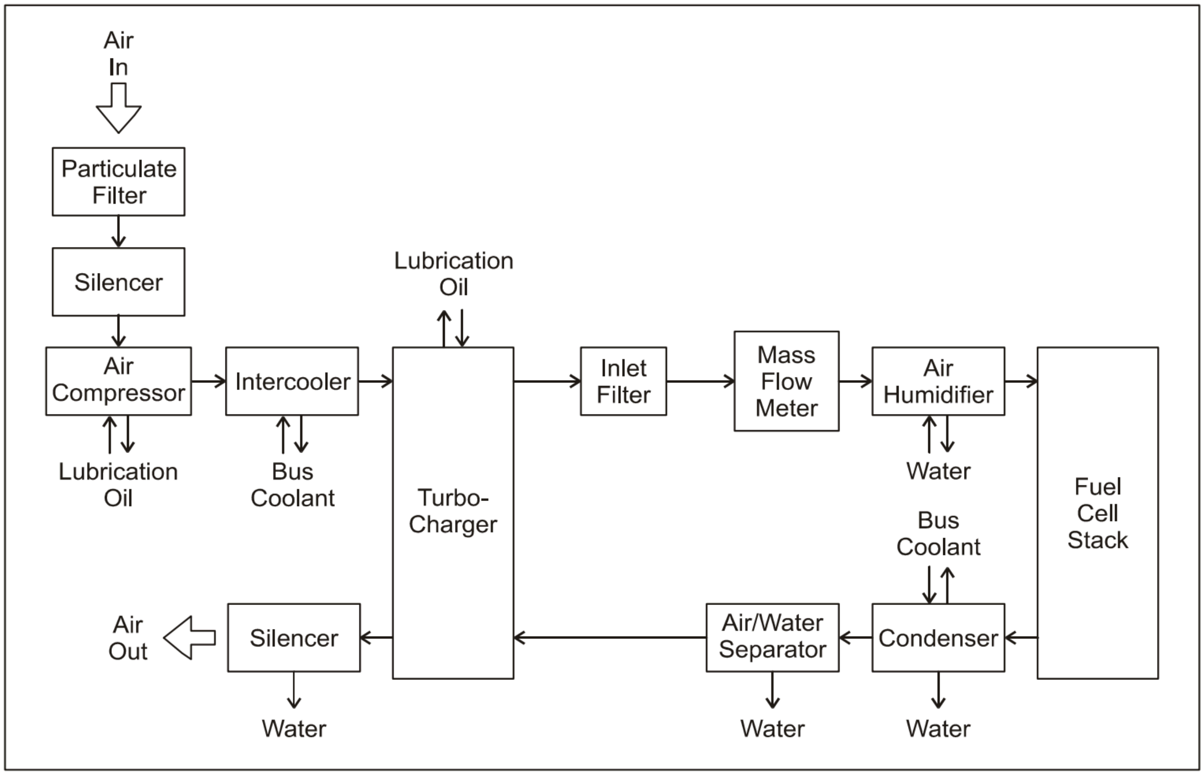


Figure 5-1 Air System Flow Diagram

Schematic of just air management system for fuel cell vehicle courtesy US DOE

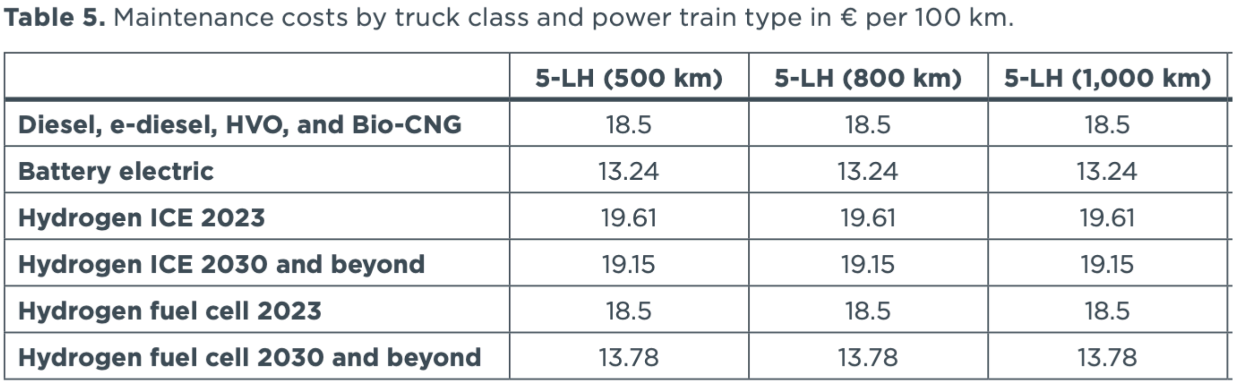


Table 5. Maintenance costs by truck class and power train type in € per 100 km.

	5-LH (500 km)	5-LH (800 km)	5-LH (1,000 km)
Diesel, e-diesel, HVO, and Bio-CNG	18.5	18.5	18.5
Battery electric	13.24	13.24	13.24
Hydrogen ICE 2023	19.61	19.61	19.61
Hydrogen ICE 2030 and beyond	19.15	19.15	19.15
Hydrogen fuel cell 2023	18.5	18.5	18.5
Hydrogen fuel cell 2030 and beyond	13.78	13.78	13.78

Table of maintenance costs for heavy trucks from ICCT total cost of ownership report

Pros of Hydrogen Fuel Cell Vehicles (Ross, 2024)

1) Energy efficiency’
2) Long driving range
3) Reduced dependency on fossil fuels
4) Quick refueling process

5) Zero emissions
6) Quiet operation
7) Lifecycle emissions- Hydrogen cars have life-cycle emissions that are at least as low as that of EVs. One study found that a hydrogen car emits around 120g/km of CO_2 over its lifetime. This number can be reduced to 60g/km if the hydrogen used is produced using renewable energy.

Cons of Hydrogen Fuel Cell Vehicles (Ross, 2024)

1) Infrastructure challenges- A) storage and transportation B) hydrogen refueling stations
2) High production costs
3) Energy-intensive production
4) Limited model availability

EVs are powered through electricity stored in a lithium-ion battery, but the electricity used to power hydrogen cars is created via a chemical reaction between hydrogen and oxygen in a fuel cell stack (Ross, 2024).

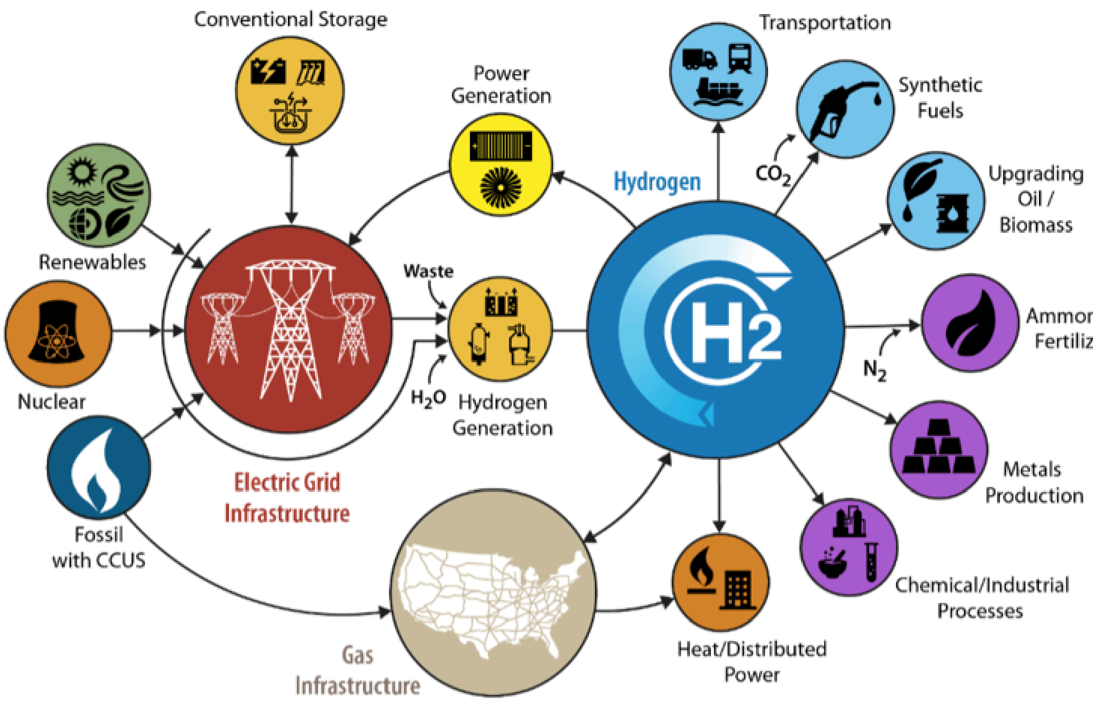
1) Step 1: Hydrogen is extracted from a range of resources, which includes fossil fuels, biomass, and water electrolysis with electricity. Most hydrogen used in the U.S. is produced at large industrial sites and transported via pipelines, high-pressure tube trailers, or liquefied hydrogen tankers.
2) Step 2: Hydrogen is compressed and stored onboard in carbon-fiber-reinforced high-pressure tanks.
3) Step 3: Compressed hydrogen is fed into an onboard fuel cell stack, where it is combined with oxygen to generate electricity. The fuel cell functions similarly to a battery. The hydrogen enters the anode where its exposure to oxygen causes the hydrogen atoms to separate into an electron and a proton.
4) Step 4: The electrons are fed, via a conductive current collector, to the vehicle's high-voltage circuitry, to power the car's electric motors that turn its wheels.
5) Step 5: Water vapor — the only by-product of the chemical reaction between hydrogen and oxygen — is released via the car's exhaust.

Hydrogen Pyrolysis for Catalyst Production

U.S. researchers have added hydrogen to iron-nitrogen-carbon catalyst fabricating process that approaches the performance of platinum and could significantly lower the costs of climate-friendly fuel cells. Finding cost-effective alternatives to platinum and other high-priced metals for use in fuel cells have focused on exploring various combinations of three readily available and less expensive materials: iron, nitrogen, and carbon. The challenge in this process is in achieving a balance between durability and efficiency in these iron-nitrogen-carbon catalysts, as while they have been successful in making the catalyst either long-lasting or high-performing, accomplishing both attributes simultaneously remains a challenge (U Buffalo, 2024).

The researchers used a fabricating process called pyrolysis to overcome this challenge, which involves using extremely hot temperatures to combine materials. During pyrolysis, four nitrogen atoms are bonded to the iron in a high-temperature chamber, and this material is then embedded into a few layers of graphene, which is a tough, light, and flexible form of carbon. Pyrolysis usually occurs within a chamber featuring an inert gas, such as argon, though the researchers fed hydrogen into the chamber to create a mixture of 90% argon and 10% percent hydrogen. Hydrogen pyrolysis allowed the researchers to more precisely control the makeup of the catalyst, as they were able to place two different iron-nitrogen-carbon compounds (one contained 10 carbon atoms, the other contained 12 carbon atoms) in positions that support durability and efficiency (U Buffalo, 2024).

Conceptual H2@scale (hydrogen at scale) energy system



Source: U.S. Department of Energy, *Hydrogen Program Plan*, Figure 3, November 2020
Note: CCUS is carbon capture, utilization, and storage.

U.S. Energy Information Administration.
https://www.eia.gov/energyexplained/hydrogen/production-of-hydrogen.php

Hydrogen Combustion in Power Plants

Burning hydrogen is an option for carbon-free power at times when the sun isn't shining, the wind is slack, and your batteries have discharged their stores. Hydrogen combustion can be achieved by mixing small amounts into the fossil-gas supply at existing plants, which produces very marginal greenhouse gas reductions at considerable cost. With the cost of hydrogen being really high in 2024, hydrogen could be used in a peaking application where the demand and price for power is really high (Spector, 2024).

Options for Carbon-free Power Plants

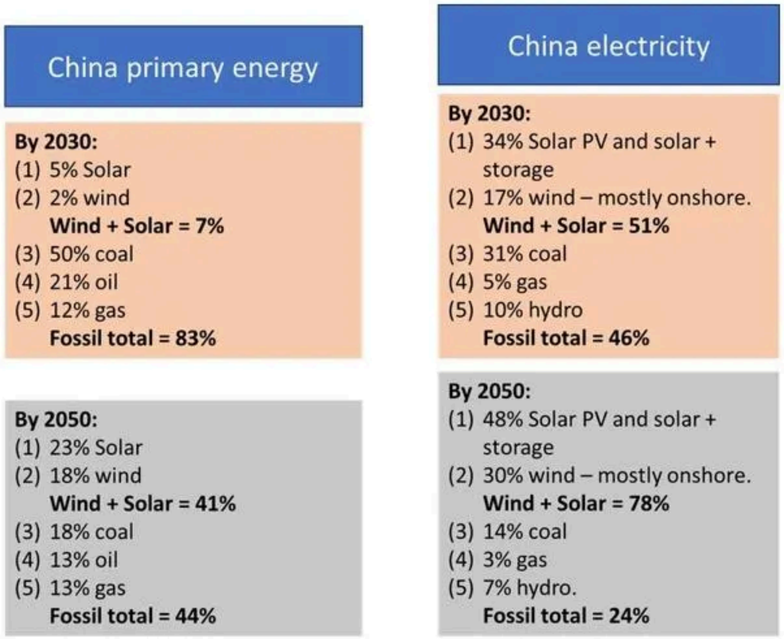
1) Long-duration batteries
2) Advanced geothermal
3) Gas plants with effective carbon capture
4) Small modular nuclear
5) Big old-school nuclear
6) Clean hydrogen combustion, tucked away in salt caverns for the big peak hours of the year when other clean power plants can't produce enough.
7) 5% hydrogen blend

The theoretical capacity to one day burn hydrogen is one way to manufacture gas turbines. Today's fleet of gas turbines in the U.S. can burn hydrogen, but both practical and legal reasons limit the amount. GE and Siemens Energy have both pledged to make all their new turbines capable of burning 100% hydrogen by 2030. Hydrogen is much less energy-dense than natural gas methane, so you need to burn more of it to get the same amount of energy output. Consequently, bigger valves, pipes and nozzles are needed to deliver higher volumes of hydrogen gas. Hydrogen also burns hotter than methane, which produces more NOx, a regulated air pollutant that needs to be mitigated. Technical and regulatory constraints currently prevent large power plants from burning more than a low-level blend of hydrogen with natural gas. However, the turbine industry is working to make standard turbine models ready to support higher levels of hydrogen. Finding hydrogen supply is the next major barrier to hydrogen combustion in power plants. For cost comparisons, in 2024 renewable hydrogen selling for $3 to $4 per kilogram equates to about $20 per million Btu. Natural gas goes for around $3 per MMBtu in 2024 (Spector, 2024).

China

On May 11, 2024, in the first phase of a 100-MWh project, a 10-MWh sodium-ion battery storage station was put into operation on in Nanning, Guangxi in southwestern China, according to China Southern Power Grid Energy Storage, the energy storage arm of Chinese grid operator China Southern Power Grid. This 100-MWh project will be able to provide 73 million kWh of clean power annually, meeting the electricity needs of 35,000 residential customers and reducing carbon dioxide emissions by 50,000 tons. In the Chinese 10-MWh sodium-ion battery energy storage station, 210 Ah sodium-ion battery cells are used that can be charged to 90 percent in 12 minutes. There is also a thermal management system that keeps the temperature difference between more than 22,000 sodium battery cells within 3 degrees Celsius, and extends the time it takes for the cells to spread thermal runaway from 30 minutes to 2 hours. In China, electrochemical storage, including lithium-ion and sodium-ion batteries, accounted for more than 95 percent of the cumulative installed capacity of China's new energy storage projects of 35.3 million kWh, by March 2024 (Zhang, 2024).

China emits the most greenhouse gasses (GHG) in the world (33%), followed by the U.S. (15%). However, China's argument is that their emissions result from industrial growth, and is only catching up to the United States and the industrial revolution. China's electrical power will grow from 30% renewables in 2024 to 55% by 2035, and 88% by 2050. In 2022 about 40% of global solar and wind capacity, separately, were installed by China. As for China's primary energy supply, from 2030 to 2050, solar and wind will increase from 7% to 41%, a multiple of 7 times. At the same time, fossil fuels will fall by half, from 83% to 44%. Renewable electricity, which by 2030 will be around 51%, will increase to 78% by 2050. In the same time frame, from 2030 to 2050, fossil-burning power plants will fall by half from 46% to 24%. Carbon emissions in China are projected to peak by 2026, according to DNV, with a 30% reduction by 2040. In 2023, China emitted a third of global emissions but this will be reduced by 70% by 2050, to only a fifth of global emissions. The keys to this reduction of emissions are displacing coal in power plants and other primary energy end use (Palmer, 2024).



China primary energy

By 2030:
(1) 5% Solar
(2) 2% wind
Wind + Solar = 7%
(3) 50% coal
(4) 21% oil
(5) 12% gas
Fossil total = 83%

By 2050:
(1) 23% Solar
(2) 18% wind
Wind + Solar = 41%
(3) 18% coal
(4) 13% oil
(5) 13% gas
Fossil total = 44%

China electricity

By 2030:
(1) 34% Solar PV and solar + storage
(2) 17% wind – mostly onshore.
Wind + Solar = 51%
(3) 31% coal
(4) 5% gas
(5) 10% hydro
Fossil total = 46%

By 2050:
(1) 48% Solar PV and solar + storage
(2) 30% wind – mostly onshore.
Wind + Solar = 78%
(3) 14% coal
(4) 3% gas
(5) 7% hydro.
Fossil total = 24%

Table 1. Progress in China's energy transition, as predicted by DNV. DNV/PALMER

PV curtailment clears up space for new renewables projects that are struggling to obtain grid connections by taking a greater percentage of generation offline. A 5% curtailment means that the utilization rates of solar and wind power projects can not fall below 95%. A 5% curtailment cap in 2018 was introduced in China by the China's National Development and Reform Commission (NDRC) and the China's National Energy Administration (NEA). In 2024, China's NEA and State Grid Corp. of China (SGCC) are contemplating whether to increase the 5% of output that can currently be curtailed from wind and solar projects. PV curtailment ensures the efficient utilization of renewable energy installations and protects the investment returns of power companies. Strict enforcement of curtailment policy imposes limitations on the scale of renewable energy projects, particularly in regions with high abandonment rates, where the approval and development of new projects is limited. As advancements in solar technologies have led to a reduction in installation costs and better returns on investment for power projects, energy companies are constrained by curtailment regulations in setting installation targets, which means that many projects struggle to secure approval for construction. China is also creating an ultra-high voltage transmission network to address the curtailment issue, which requires substantial investment (Shaw, 2024).

China is trying to pivot from its economic reliance on the real estate industry to new energy industries like solar, electric vehicles, and lithium-ion batteries. 80% of solar panels are made in China, and the solar-panel market is in a state of oversupply, which means manufacturers in the US and Europe mus reduce prices. Solar-panel supply globally is forecast to reach 1,100 gigawatts by the end of 2024, three times more than demand, according to a 2024 International Energy Agency report. Prices on the spot market fell by half in 2023 and are likely to extend decline by another 40% by 2028. In fact, solar panels are so cheap that they're now being used to line garden fences in Germany and the Netherlands, the Financial Times reported in 2024. Putting solar panels on fences saves on pricey labor and scaffolding costs required for roof installations, as solar panels are typically installed on rooftops, where they can capture the most sunlight (Tan, 2024).

In 2024, the Biden Administration raised the tariff rates on solar cells imported from China from 25% to 50%. They also raised tariff rates on aluminum and steel imported from China, from 0% to 7.5% up to 25%, as well as those applied to semiconductors, from 25% to 50%. Tariffs on electric vehicles were raised from 25% to 100% and those on lithium-ion EV batteries from 7.5%% to 25%. The U.S. government has also increased the tariffs on ship-to-shore cranes and medical products (Bellini, 2024B).

United States

In the U.S., Natron in 2024 announced plans for a new sodium-ion battery plant in a repurposed lithium-ion battery plant to produce 600 megawatts worth of the new sodium-ion battery per year. These Natron batteries will address the growing energy storage needs of data centers, including the explosive growth of AI technology that will fuel more demand for energy storage and 24/7 power at data centers in the US. Natron envisions gigawatt-scale sodium-ion battery factories to follow, targeting additional markets including off-road industrial vehicles and EV fast charging stations, as well as the telecom field. Natron’s 8-kilowatt, 50-volt battery tray is primarily designed to manage peak loads at data centers and provide emergency backup power, but emerging markets like EV fast charging stations and grid-scale storage are also targeted (Casey, 2024).

In September of 2020, Natron received a $19.9 million award from the Energy Department’s ARPA-E office for funding high-risk, high-reward projects, with the goal of helping to open the Natron factory. “The project aims to scale up production of Natron Energy’s (Natron) Prussian blue electrode sodium-ion batteries by 30x to 18,000 trays per year, and fully de-risk the resulting supply chain and products through continuous production and sales for six months,” ARPA-E explained. “Natron’s tray provides data center operators up to 2x higher power density and 10x longer cycle life than existing products, along with superior safety performance," ARPA-E adds. Natron launched in 2012 with a stated mission to develop an electrolyte formula that stabilizes the protective film of the anode (Casey, 2024).

In October 2023, ARPA-E awarded $3,198,085 to the Massachusetts firm 24M Technologies to develop a new sodium-ion battery specifically for EVs. "24M's cell design will incorporate (1) its ultra-thick SemiSolid cathode made up of advanced cobalt-free, nickel-free sodium cathode active material, (2) an advanced wide-temperature, fast-charging electrolyte developed using machine learning and automated high-throughput screening technology, and (3) a sodium super ionic conductor," ARPA-E explained (Casey, 2024).

Argonne has been replicating the nickel-manganese-cobalt (NMC) cathode strategy for sodium battery research. The result is a layered sodium nickel-manganese-iron oxide formula that allows for the efficient insertion and extraction of sodium. "The absence of cobalt in the cathode formula mitigates cost, scarcity and toxicity concerns associated with that element," the lab notes. A research team at Argonne developed the lithium nickel-manganese-cobalt (NMC) cathode material for EV batteries, which General Motors deployed in its Chevy Volt and Bolt cars. The key to the NMC architecture was to arrange the atoms in layers, enabling the lithium to flow more efficiently (Casey, 2024).

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Jeff Madura, center, recipient of the
2010 Distinguished Doctoral Alumni Award, poses
with FSU College of Business
Dean Caryn Beck-Dudley, left, and Finance Dept.
Chair Bill Christiansen, right.

Jeff Madura, who earned his DBA in finance from The Florida State University College of Business in 1983, was awarded the Distinguished Doctoral Alumni Award on April 23, 2010, in Tallahassee.

The Distinguished Doctoral Alumni Award was established in 2007 for the purpose of recognizing high-quality doctoral graduates and their outstanding professional achievements. The award honors alumni who have utilized their education and experience to achieve significant levels of success and distinction through their high level of performance. The recipients are selected from among accomplished senior scholars who received a doctorate from one of the departments in the College of Business. Recognizing the recipients brings pride and distinction to the College of Business at Florida State University.

Professor Madura is the SunTrust Bank Professor of Finance at Florida Atlantic University. His research covers international finance, corporate finance, corporate governance and financial markets. He has more than 100 publications in academic journals, including the *Journal of Financial and Quantitative Analysis, Financial Management*, the *Journal of Financial Research*, and *Financial Review*. He has won various research awards, including Outstanding Paper at the *Journal of Financial Research* and at *Financial Review*, Researcher of the Year for the College of Business at University of Central Florida and at Florida Atlantic University. Professor Madura is ranked sixth among the leading publishers in the top 26 journals in finance.

Professor Madura has written numerous textbooks, including "International Financial Management" (now in its 10th edition), "Financial Markets and Institutions" (now in its 9th edition), "Introduction to Business" (now in its 5th edition), and "Personal Finance" (now in its 4th edition). His textbooks have been translated into multiple languages, including Spanish, Portuguese, Indonesian and Chinese. He has served as a consultant for multinational corporations, as the director for the Southern Finance Association and Eastern Finance Association, and as president of the Southern Finance Association.

RICHARD HUDSON
8TH DISTRICT, NORTH CAROLINA

COMMITTEE ON ENERGY AND COMMERCE
SUBCOMMITTEE ON ENERGY
SUBCOMMITTEE ON ENVIRONMENT
SUBCOMMITTEE ON HEALTH

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March 15, 2019

Mr. Kevin Sleem
3528 Turnberry Cir
Fayetteville, NC 28303-4664

Dear Mr. Sleem:

Thank you for contacting me regarding H.R. 227, the *Multinational Species Conservation Funds Reauthorization Act* . We completely agree on the need to protect and preserve our wildlife populations, particularly our endangered species. This is why I have supported numerous bills to protect our environment to ensure these species have thriving habitats.

As someone who loves and appreciates animals, I understand the importance of taking care of our most vulnerable wildlife. Additionally, as a lifelong outdoorsman who grew up right here in North Carolina, I know that caring for the environment is our duty and we must preserve our lands now and for future generations. I believe it is extremely important to be good stewards of the environment and I am committed to fighting for the responsible management of our wildlife.

As you may know, H.R. 227 was introduced in the 115 th Congress by Representative Don Young (R-AK) on January 3, 2017. While this legislation has not been reintroduced in the 116th Congress, please know I will keep your thoughts in mind should I have the opportunity to consider this or similar legislation this Congress.

Again, thank you for taking the time to share your views. Your opinions are important, so please continue to write, call, or email me with any concerns you may have in the future. For more information on issues impacting North Carolinians, please visit our website at http://hudson.house.gov and sign up for our weekly newsletter.

Sincerely,

Richard Hudson

Richard Hudson
Member of Congress

UNITED STATES DEPARTMENT OF EDUCATION
OFFICE FOR CIVIL RIGHTS, REGION IV

61 FORSYTH ST., SOUTHWEST, SUITE 19T10
ATLANTA, GA 30303-8927

REGION IV
ALABAMA
FLORIDA
GEORGIA
TENNESSEE

August 29, 2023

Via email only: sleemkevin@gmail.com
Mr. Kevin Sleem
3528 Turnberry Circle
Fayetteville, North Carolina 28303

Re: OCR Complaint #04-23-2022

Dear Mr. Sleem:

The U.S. Department of Education, Office for Civil Rights (OCR), has completed its investigation of your complaint against Florida Atlantic University (University) received on November 1, 2022 alleging discrimination based on national origin. Where appropriate this letter will refer to you as the Complainant.

OCR enforces Title VI of the Civil Rights Act of 1964 (Title VI), 42 U.S.C. §§ 2000d et seq., and its implementing regulation, 34 C.F.R. Part 100, which prohibit discrimination on the basis of race, color, or national origin by recipients of Federal financial assistance from the Department of Education. As a recipient of Federal financial assistance from the Department of Education, the University is subject to Title VI and to OCR's jurisdiction.

You told OCR that you first enrolled in the PhD program at the University's Business School in fall 2008. You stated that you were dismissed from the program in November 2008 because of your grade point average. You stated that you applied for enrollment at another university that requires references from previous instructors. You stated that you emailed a professor from the College of Business on September 29, 2022 to request a reference but did not receive a response. You alleged that you did not receive a response to your request because you have U.S. and Jamaican citizenship.

OCR enforces Title VI of the Civil Rights Act of 1964 (Title VI), 42 U.S.C. §§ 2000d et seq., and its implementing regulation, 34 C.F.R. Part 100, which prohibit discrimination on the basis of race, color, or national origin by recipients of Federal financial assistance from the Department of Education. As a recipient of Federal financial assistance from the Department of Education, the University is subject to Title VI and to OCR's jurisdiction.

OCR investigated whether the University discriminated against the Complainant on the basis of national origin, in violation of Title VI and its implementing regulation at 34 C.F.R. §100.3. OCR interviewed the Complainant and the Graduate College Program Assistant who was responsible for responding to email inquiries directed to the Graduate College. We also reviewed documents provided by the Complainant and the University including email correspondence between the Complainant and the University employees.

Legal standards

The regulation implementing Title VI at 34 C.F.R. Section 100.3(a), (b)(1)(i)-(iii) and (2) provides that no person shall, on the ground of race, color or national origin, be excluded from participation in, be denied the benefits of, or be otherwise subjected to discrimination under any program to which the regulation applies. A recipient may not, on the ground of race, color or national origin, subject an individual to segregation or separate treatment in any matter related to his receipt of any service, financial aid, or other benefit under the program. Further, a recipient may not, on the ground of race, color, or national origin, deny an individual any service or other benefit, provide any service in a different manner from that provided to others, or subject an individual to segregation or separate treatment under the program.

When investigating an allegation of different treatment, OCR first determines whether there is sufficient evidence to establish an initial, or prima facie, case of discrimination. Specifically, OCR determines whether a school treated an individual less favorably than similarly situated individuals of a different national origin. If so, OCR then determines whether the school had a legitimate, nondiscriminatory reason for the different treatment. Finally, OCR determines whether the reason given by the school is a pretext, or excuse, for unlawful discrimination.

Factual findings

The Complainant, a former University student, was last enrolled at the University during the fall 2008 semester; during that term he was in the Ph.D. program in Finance in the University's College of Business.

The Complainant told OCR that on September 29, 2022, he emailed a former professor in the College of Business to request that a professor provide a reference to North Carolina State University (School), but he did not receive a response. He asserted that he did not receive a response to his request because of his national origin.

According to the University's Civil Rights Investigator, the University conducted an email search and did not locate the email that the Complainant described, but did locate a request for recommendations submitted by the School. The University's Civil Rights Investigator reported that auto-generated emails were sent to the University Graduate College's general email account, and not to a particular University employee's email account. The request was addressed: "Dear [the former professor whom the Complainant identified]." The University advised OCR that the Complainant's former professor retired and is no longer employed by the University.

On December 1, 2022, the Graduate College Program Assistant, who monitors the Graduate College's email account, responded to the request, stating that "the Graduate College does not provide letters of recommendation as we do not know the student on a personal basis."[1] In an

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[1] The University received similar letters of recommendation requests on behalf of the Complainant from three universities.

interview with OCR, the Graduate College Program Assistant stated that she did not know the Complainant, and likewise was unaware of his national origin.

According to information provided by the University's representative in response to OCR's request for information, the University's College of Business does not request or require that faculty write letters of recommendation on behalf of students and does not maintain records regarding issuance of such letters

Analysis

The evidence does not substantiate that the University received from the Complainant a request for a letter of recommendation from the professor to support the Complainant's application to the School. When the University received a request from the School through the Graduate College email account, the Graduate College Program Assistant, who had no knowledge of the Complainant, replied that the College does not provide recommendations for students. In light of the representative's statement that the University does not request or require that faculty provide letters of recommendation, the response to the School's request does not indicate any different treatment of the Complainant. Nor is there other evidence of possible national origin-based different treatment since the Graduate College Program Assistant did not know the Complainant's national origin. The evidence therefore does not support that the University discriminated against the Complainant on the basis of national origin, as alleged.

Conclusion

Accordingly, OCR found insufficient evidence to support a finding of a violation of the applicable regulation.

This concludes OCR' s investigation of the complaint. This letter should not be interpreted to address the University's compliance with any other regulatory provision or to address any issues other than those addressed in this letter.

This letter sets forth OCR' s determination in an individual OCR case. This letter is not a formal statement of OCR policy and should not be relied upon, cited, or construed as such. OCR' s formal policy statements are approved by a duly authorized OCR official and made available to the public. The Complainant may have a right to file a lawsuit in federal court whether or not OCR finds a violation.

Please be advised that the University must not harass, coerce, intimidate, discriminate, or otherwise retaliate against an individual because that individual asserts a right or privilege under a law enforced by OCR or files a complaint, testifies, assists, or participates in a proceeding under a law enforced by OCR. If this happens, the individual may file a retaliation complaint with OCR.

Under the Freedom of Information Act, it may be necessary to release this document and related correspondence and records upon request. If OCR receives such a request, we will seek to protect, to the extent provided by law, personally identifiable information, that, if released, could reasonably be expected to constitute an unwarranted invasion of personal privacy.

If you have any questions regarding this letter, please contact Philip Weltner, Senior Attorney, at (202) 987-1891or me, at (404) 974-9356.

Sincerely,
Wendy Gatlin
Compliance Team Leader