

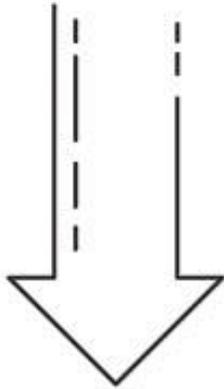
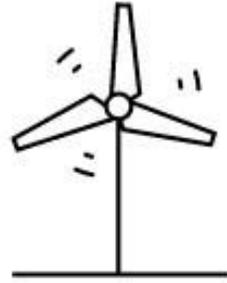
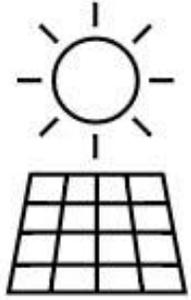
Sustainable Sundays Speaker Series

Storing Renewable Energy

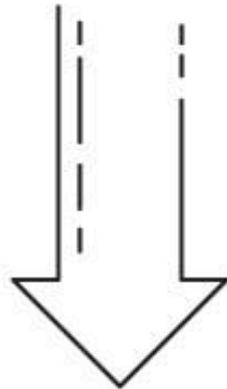
Thomas Theis



The cost of renewable energy is rapidly decreasing.



85%



49%

Cost drops since 2010

Source: [BloombergNEF](#)

In addition to falling prices, invention and innovation are increasing the value and attractiveness of renewable energy, often in surprising ways.

“Agrivoltaics”

Land around and under solar panels is being used to grow food, raise livestock, and provide habitat for bees and other pollinators.



Pollinator-friendly plantings around solar photovoltaic arrays

Source: [CleanTechnica](#)

Farming under solar panels

Image Credit: National Renewable Energy Lab

Source: [Reasons to be Cheerful](#)

Off-shore Wind

Steadier and stronger ocean winds means more power from each turbine.

Cost is approaching that of on-shore wind.



Simulated view of view of wind turbines 16 miles off-shore from Atlantic City

Block Island Wind Farm: Scientists observe increased diversity of sea life around and on turbine structures.

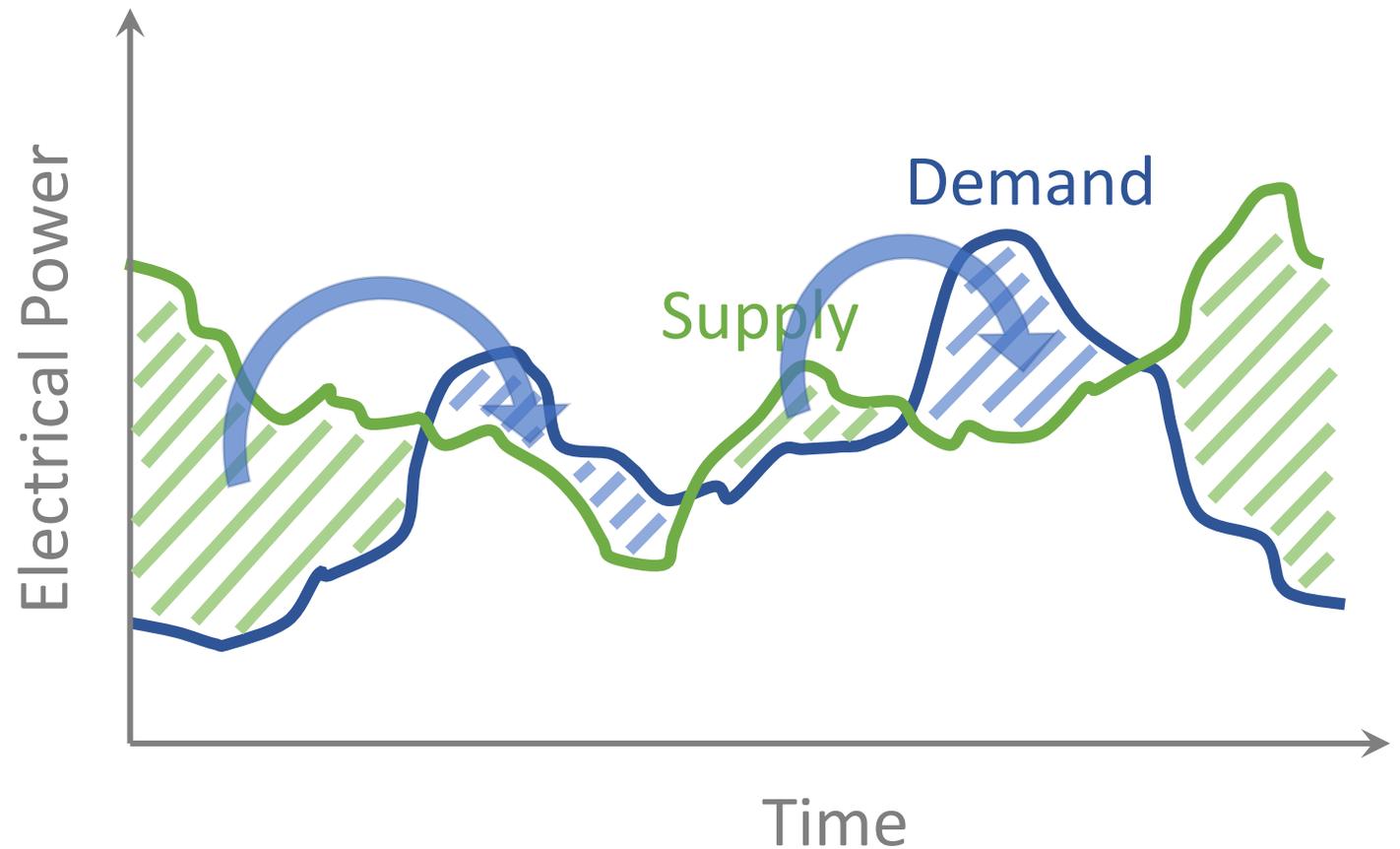
Source: [Block Island Times](#)



Wind and solar power are now *the* lowest-cost sources of electrical power in much of the world, but wind and sunlight are highly variable.

Our need for electrical power is also variable, but it doesn't match the availability of wind and sunlight.

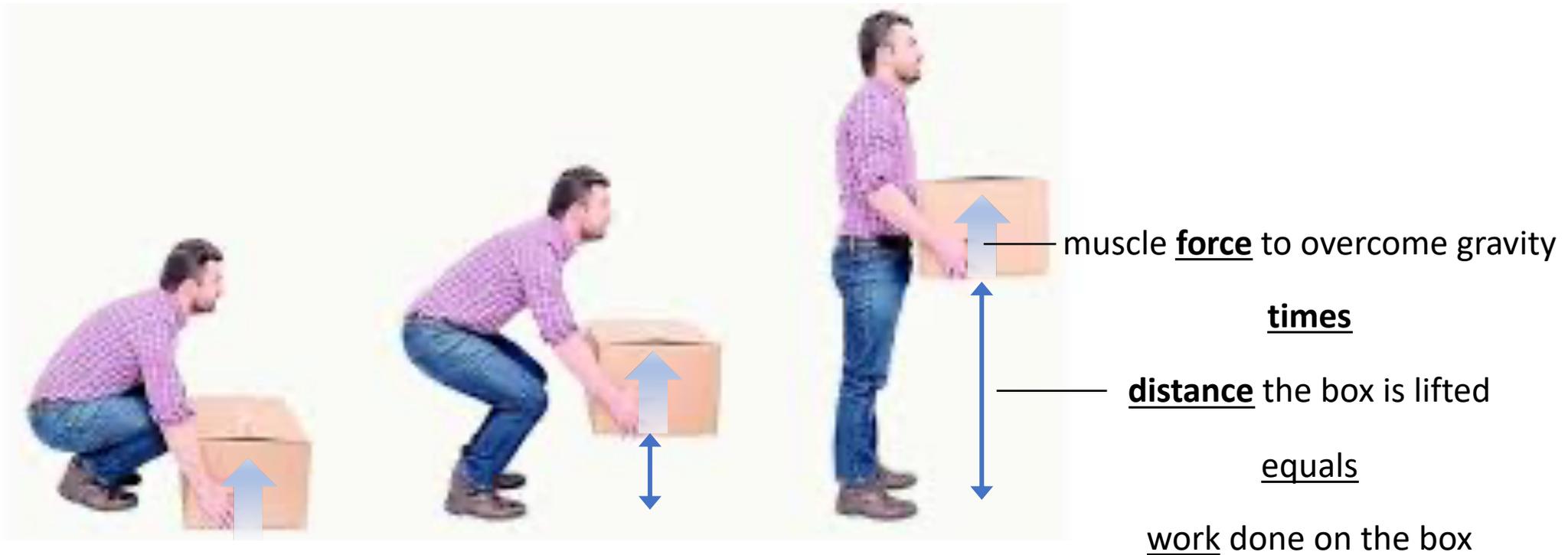
We need a way to store energy when wind and sunlight are plentiful, for use when wind and sunlight are scarce.



What is *energy*?

Energy is *the capacity to do work*.

Work is the act of *exerting a force over a distance*.



What is *power*?

Power is the *rate* at which energy is produced or consumed.

Lifting the box quickly requires more power than lifting it slowly.



Measuring Power and Energy

Electrical *power* is measured in *watts*.

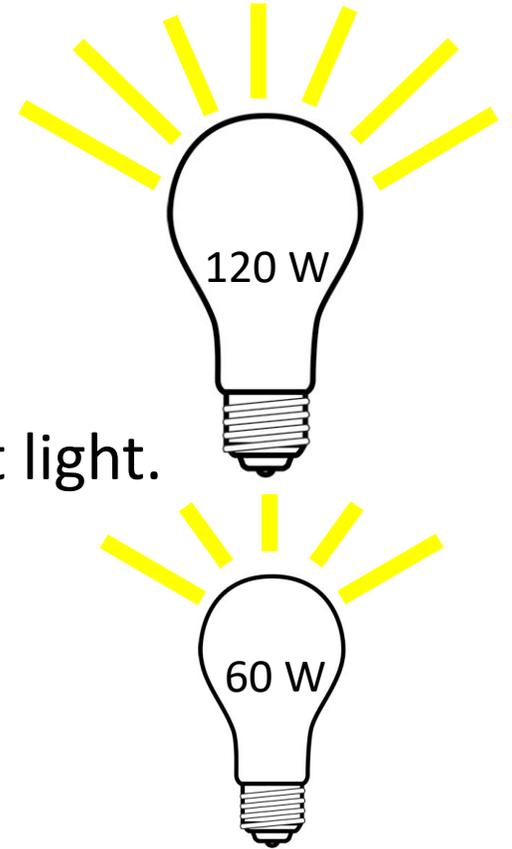
(1000 watts = 1 kilowatt or 1 kW.)

A 120 watt light consumes energy at twice the *rate* of a 60 watt light.

Energy = Power x Time.

Thus, electrical *energy* is measured in *watt-hours*.

(1000 watt-hours = 1 kilowatt-hour or 1 kWh)



ConEd bills you by the kilowatt-hour, so your electricity bill is an *energy* bill.
To reduce your bill, reduce *watts* (switch to LED bulbs) or reduce *hours* of use.

Storing Energy



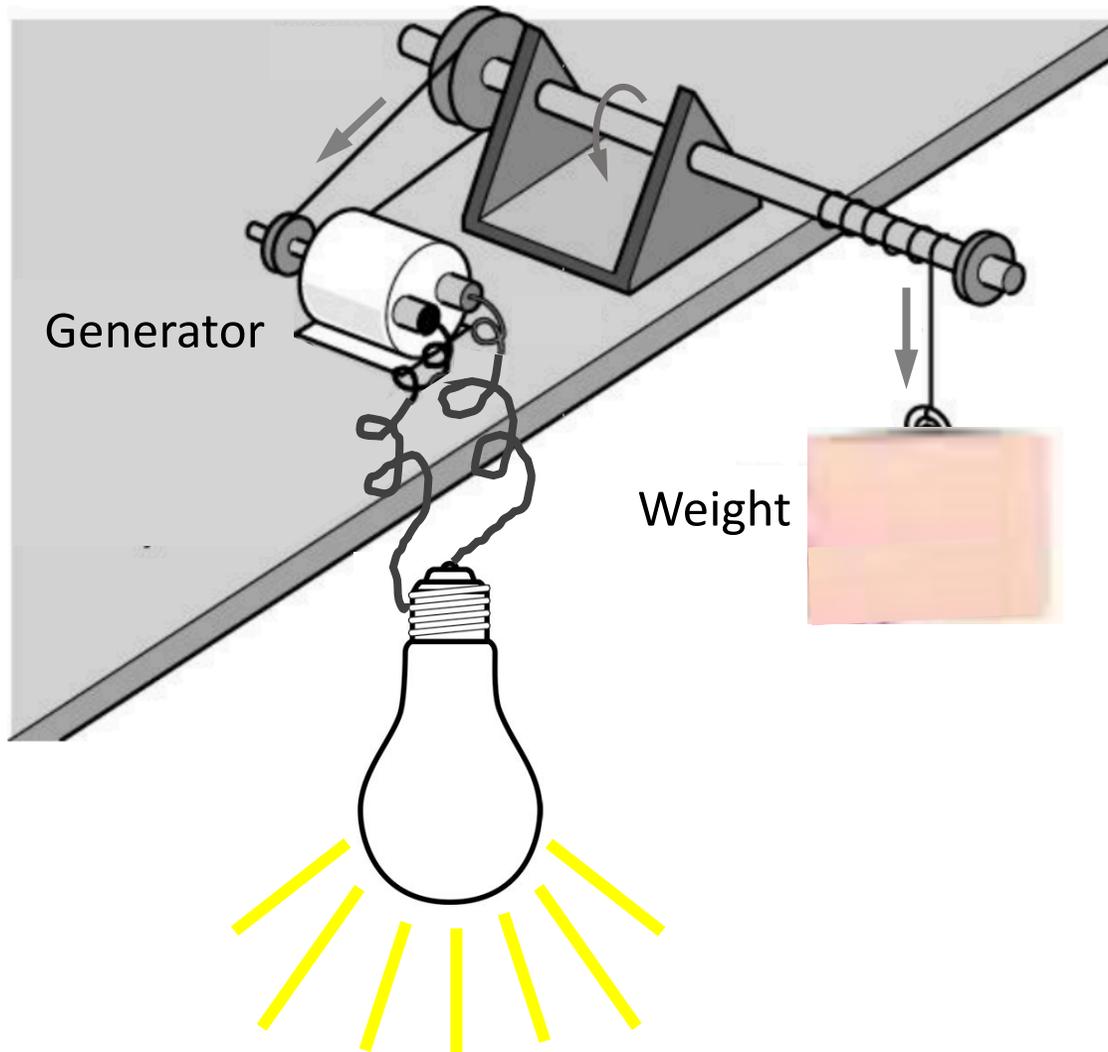
The act of lifting the box stored energy in the box!

We can prove it by letting go of the box.

The stored energy is released as noise, bending or breaking of box contents, and perhaps bruising of toes.

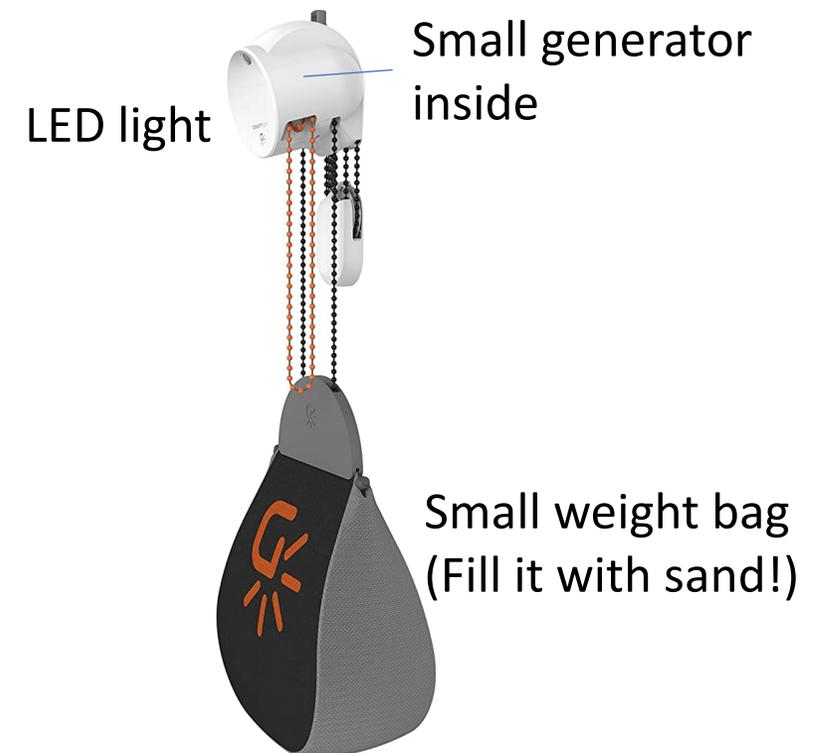
Problem: The stored energy did not do any useful work!

Here's a more useful way to release the energy stored in a weight that's been lifted against the force of gravity.



Does this mechanism seem impractical?

Here's a practical version you can buy!
(Just do a search for "gravity light".)

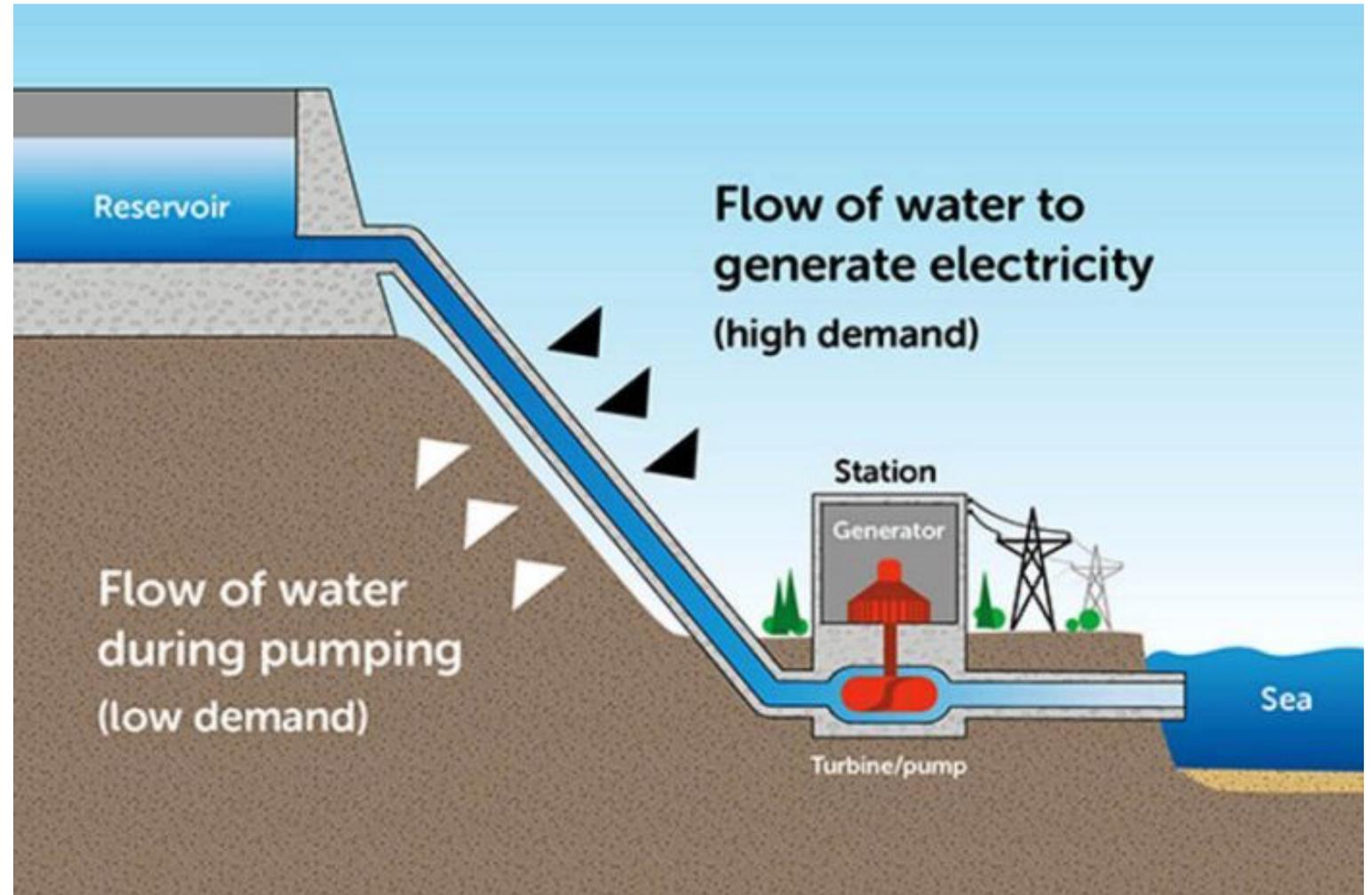


By lifting heavier weights larger distances, we can store more energy and release it faster.

**Example:
Stored Hydropower**

When electricity is cheap, use it to pump water up hill.

When electricity is expensive, run water downhill to generate electricity.



Gravity based systems are great for storing a lot of energy for a long time, but we'd like to have a system that ...

- stores more energy in a smaller volume
- returns nearly all the energy that it stores
- comes in a wide range of sizes and forms
- operates silently and without emissions
- responds quickly to changes in electrical supply and demand

... which brings us to rechargeable batteries.

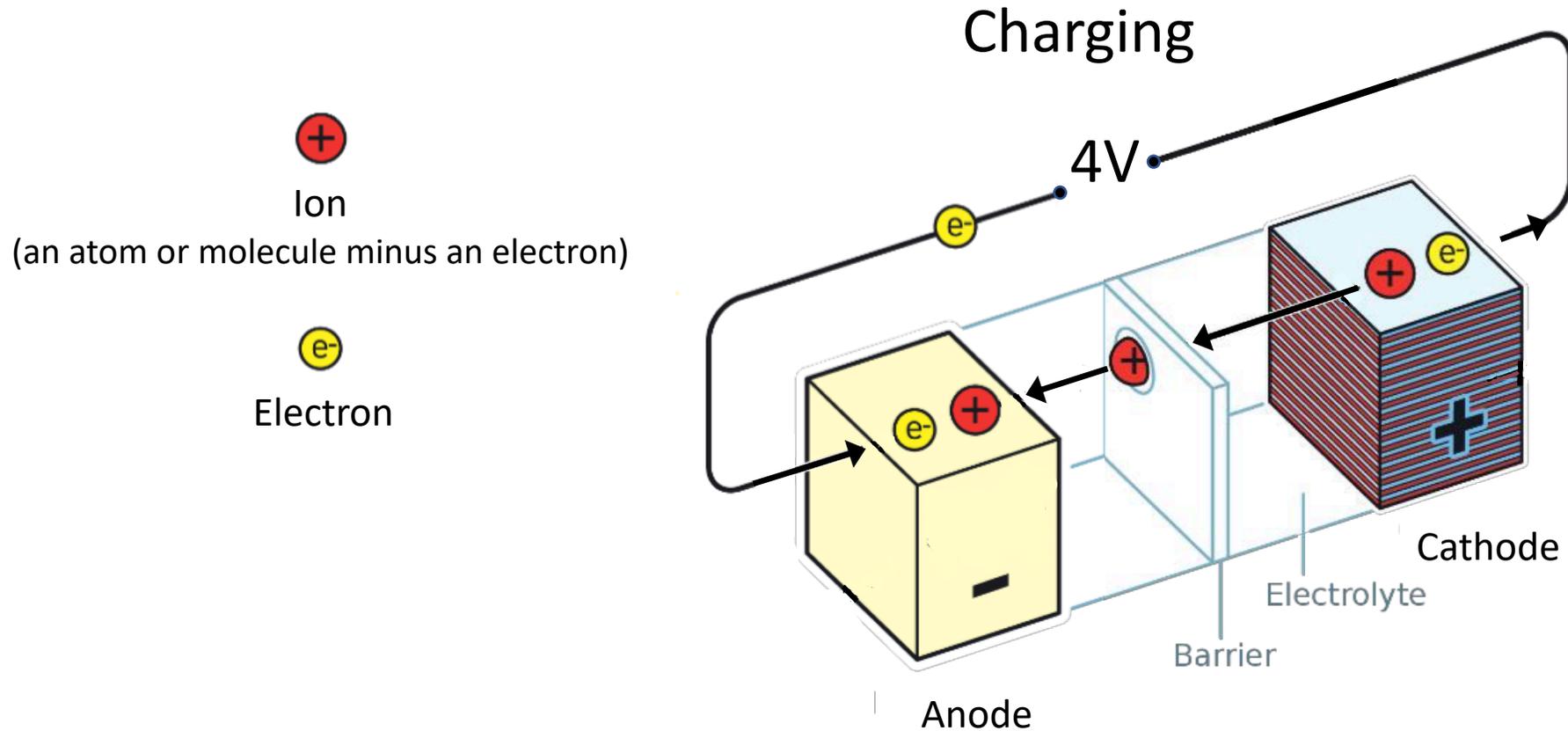


Figure modified from source:

<https://www.nobelprize.org/uploads/2019/10/advanced-chemistryprize2019.pdf>

... which brings us to rechargeable batteries.

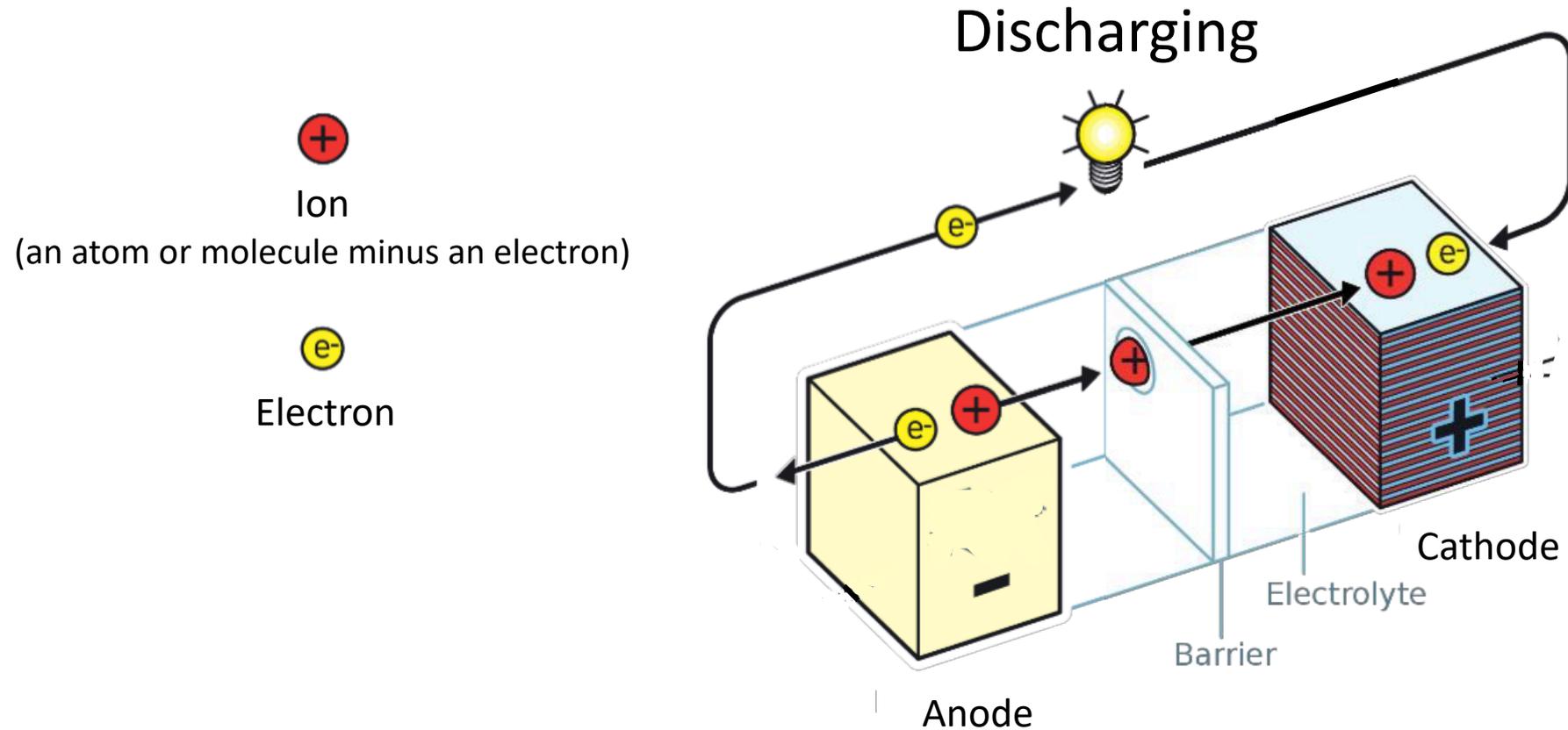


Figure modified from source:

<https://www.nobelprize.org/uploads/2019/10/advanced-chemistryprize2019.pdf>

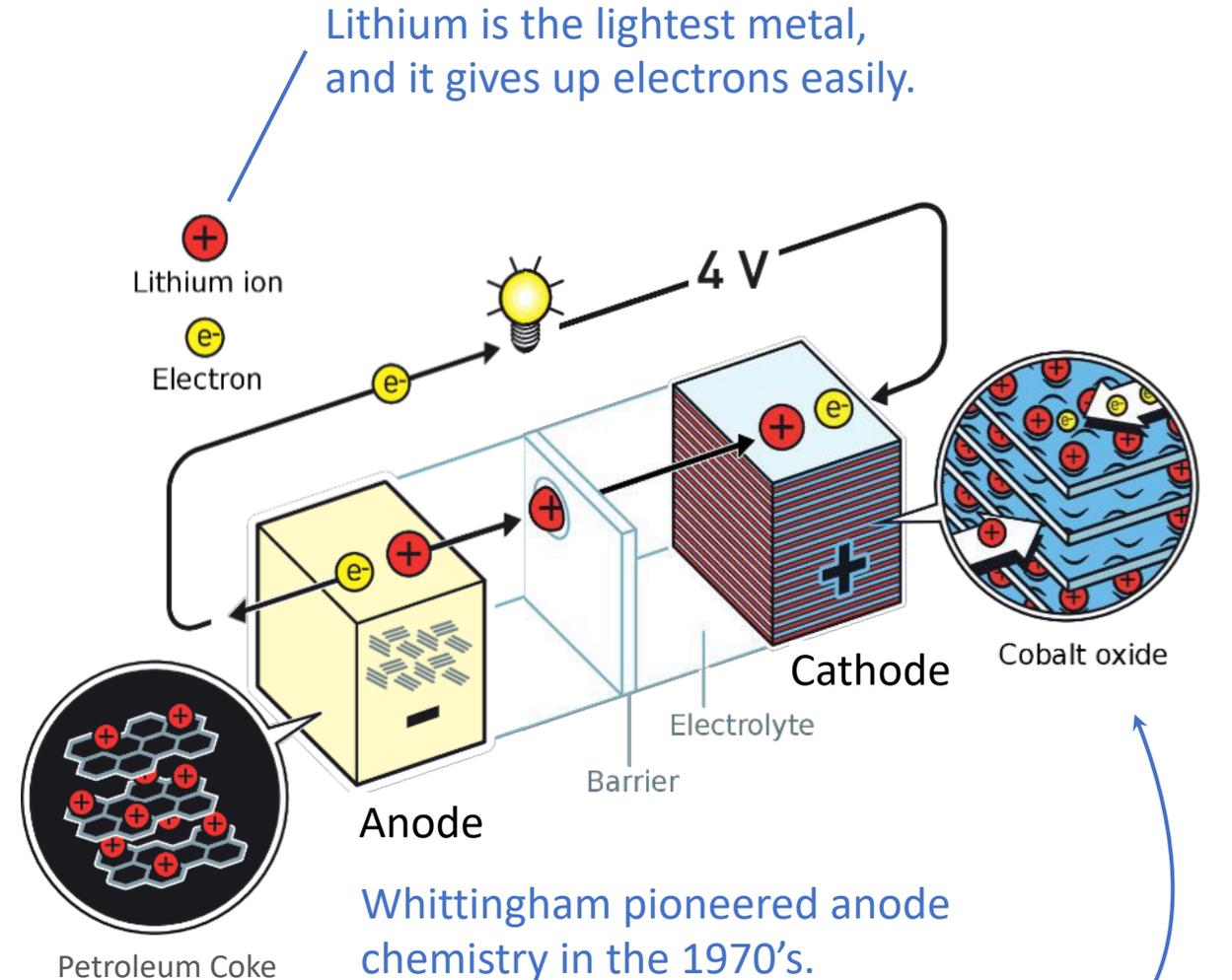
The Lithium Ion Battery

They created a rechargeable world.



Credit: Mitch Jacoby/C&EN; Binghamton University; The Japan Prize Foundation

John B. Goodenough (left), M. Stanley Whittingham, and Akira Yoshino won the 2019 Nobel Prize in Chemistry “for the development of lithium-ion batteries.”

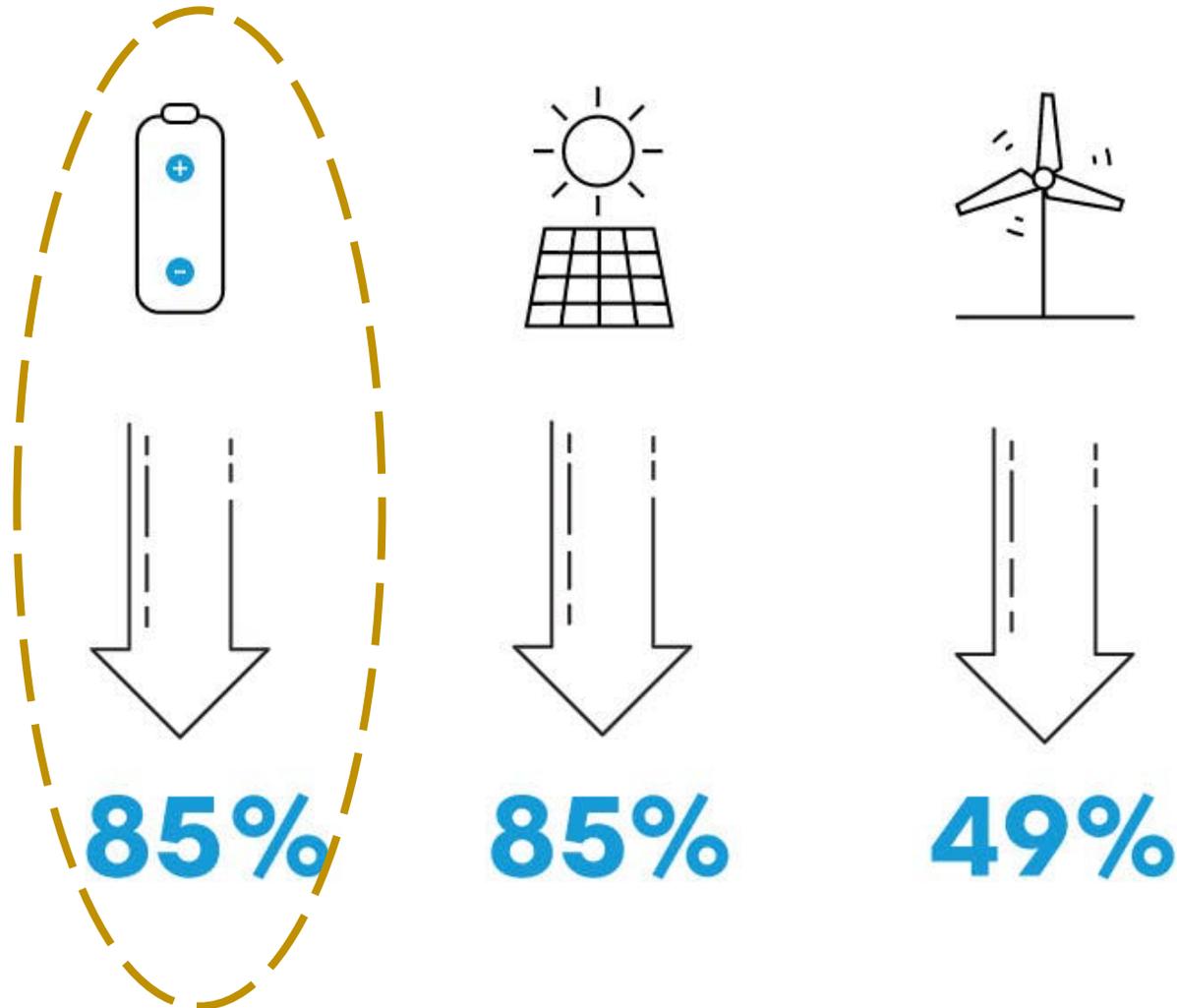


Whittingham pioneered anode chemistry in the 1970's.

Goodenough demonstrated cobalt oxide cathodes in the 1980's.

Yoshino further advanced anode materials. These cascading advances allowed hundreds of charge/discharge cycles by the 1990s.

Great News! Lithium-ion battery cost has dropped along with the costs of renewable energy ...



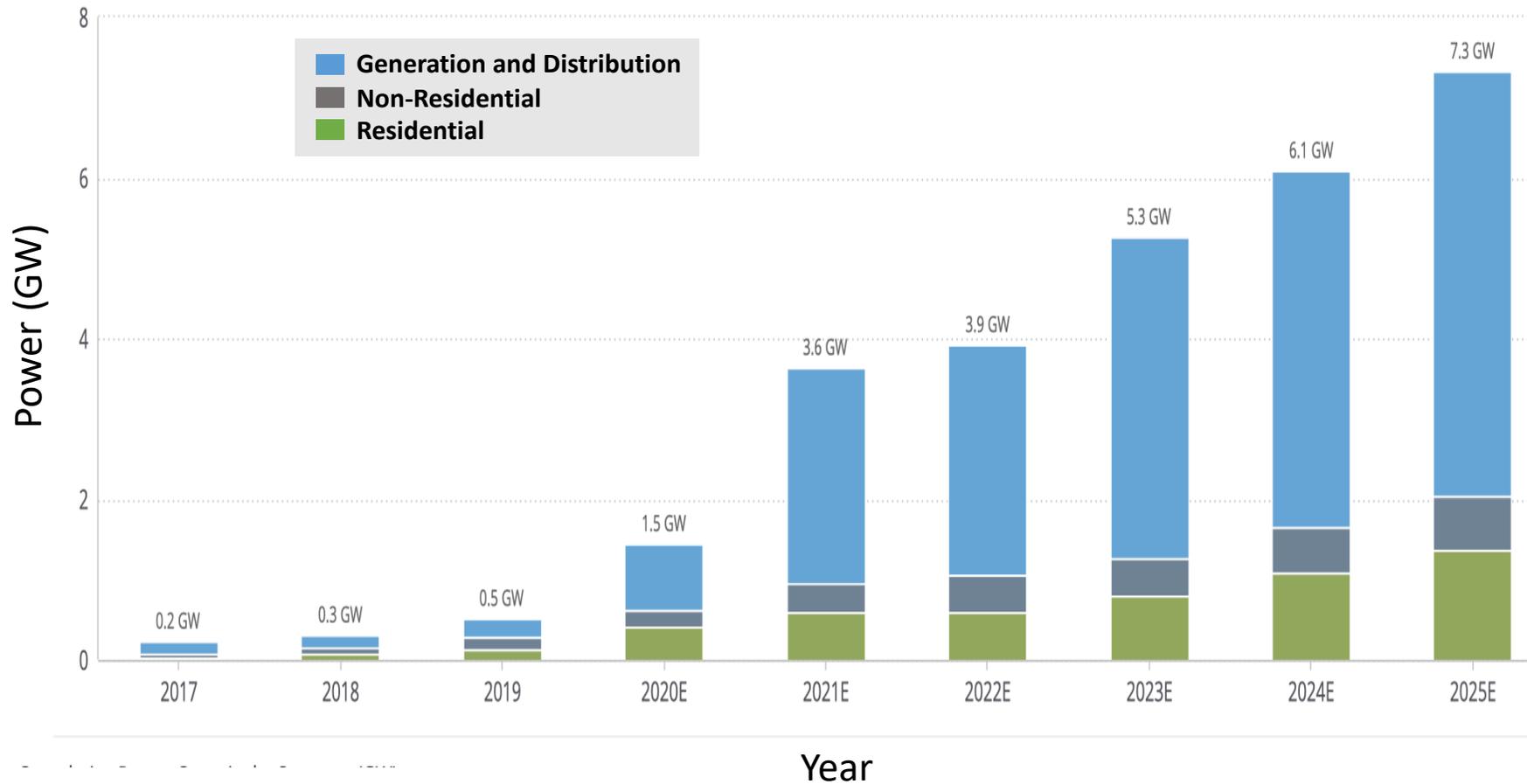
Cost drops since 2010

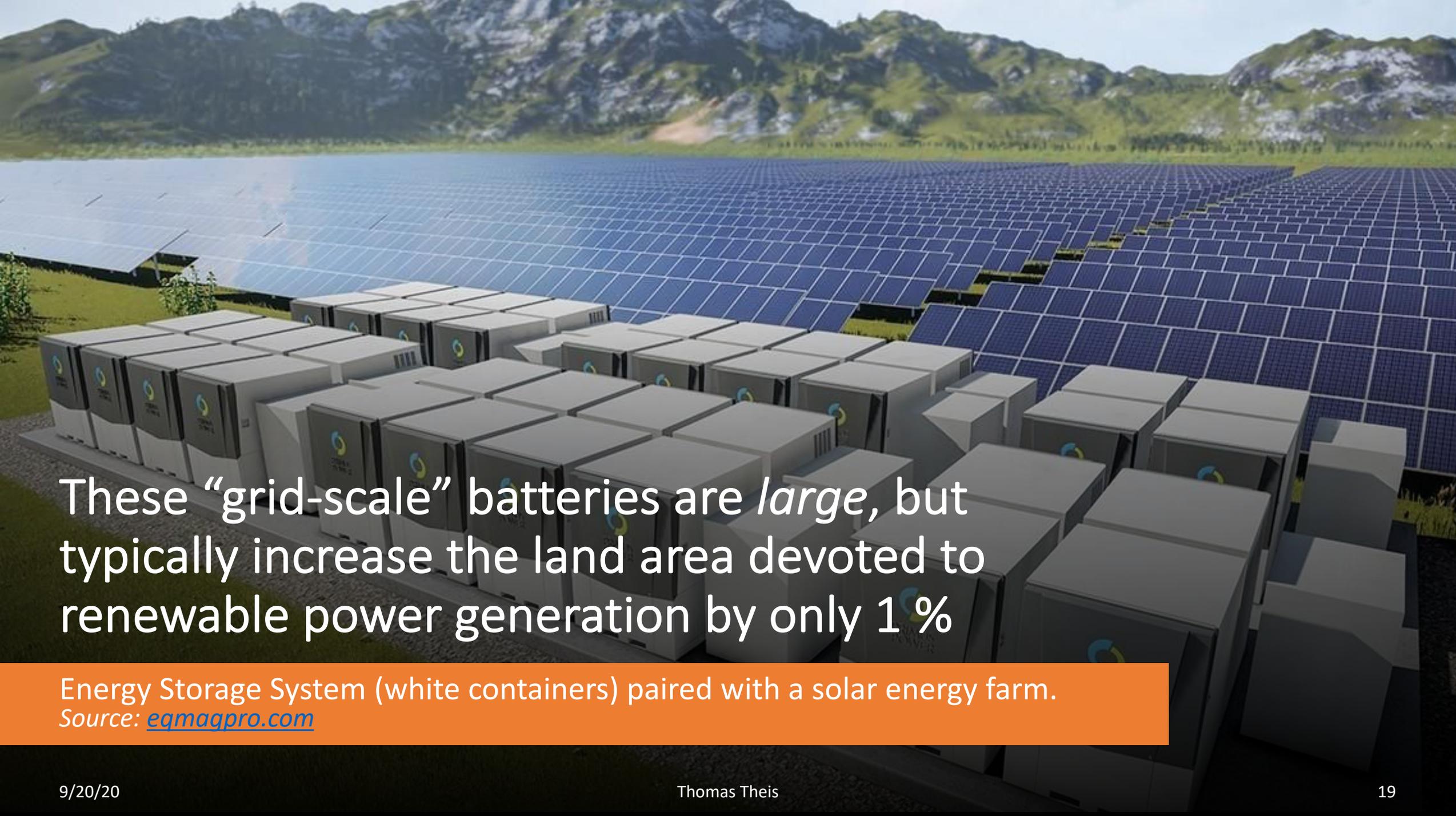
Source: [BloombergNEF](#)

... and investment in battery energy storage systems has exploded.

Annual Power Capacity Additions (GW) in North America

Source: WoodMac Global Energy Storage Forecasts





These “grid-scale” batteries are *large*, but typically increase the land area devoted to renewable power generation by only 1%

Energy Storage System (white containers) paired with a solar energy farm.

Source: eqmagpro.com



Sized to fit their purpose, silent in operation, and free of emissions, they can be installed nearly anywhere.

Energy Storage System at an Electrify America electric vehicle charging station.

Source: electrek.co

These batteries are changing the generation, distribution, and use of electrical power in profound ways.

Renewable Generation

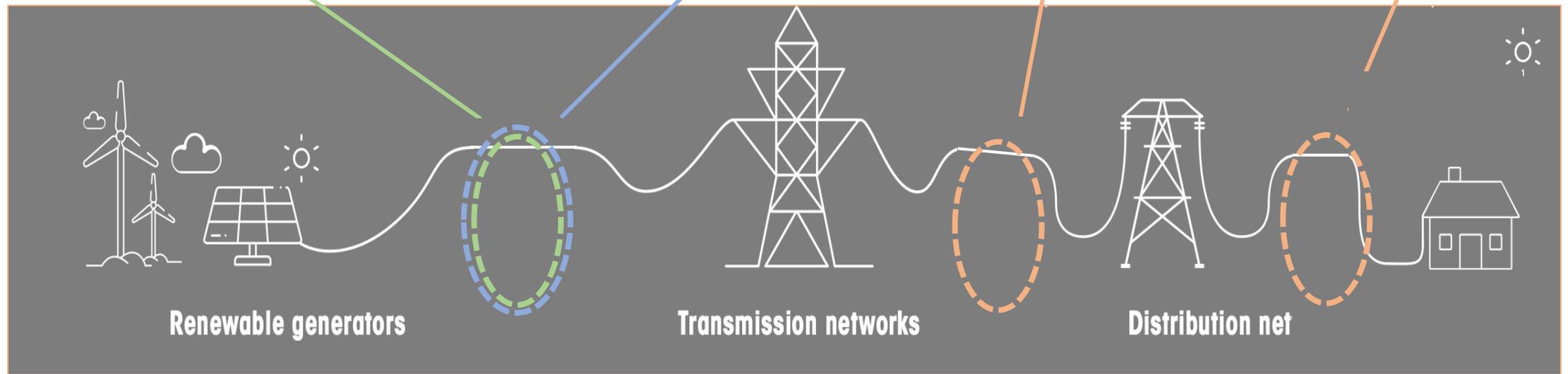
- Reduced curtailment
- Capacity firming
- Peaking

Grid Reliability

- Frequency regulation
- Flexible ramping
- Black start services
- Energy trading

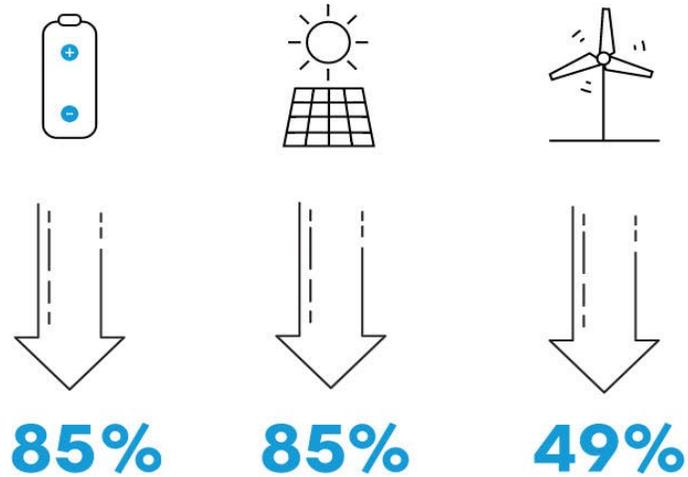
Investment Deferral

- Transmission and distribution congestion relief
- Energy shifting and capacity investment deferral



Source: [International Renewable Energy Agency \(IRENA\)](https://www.irena.org/)

Why *do* costs often drop quickly for emerging technologies?



Basically, it's common sense:

When we do a task again and again, we get better at it.

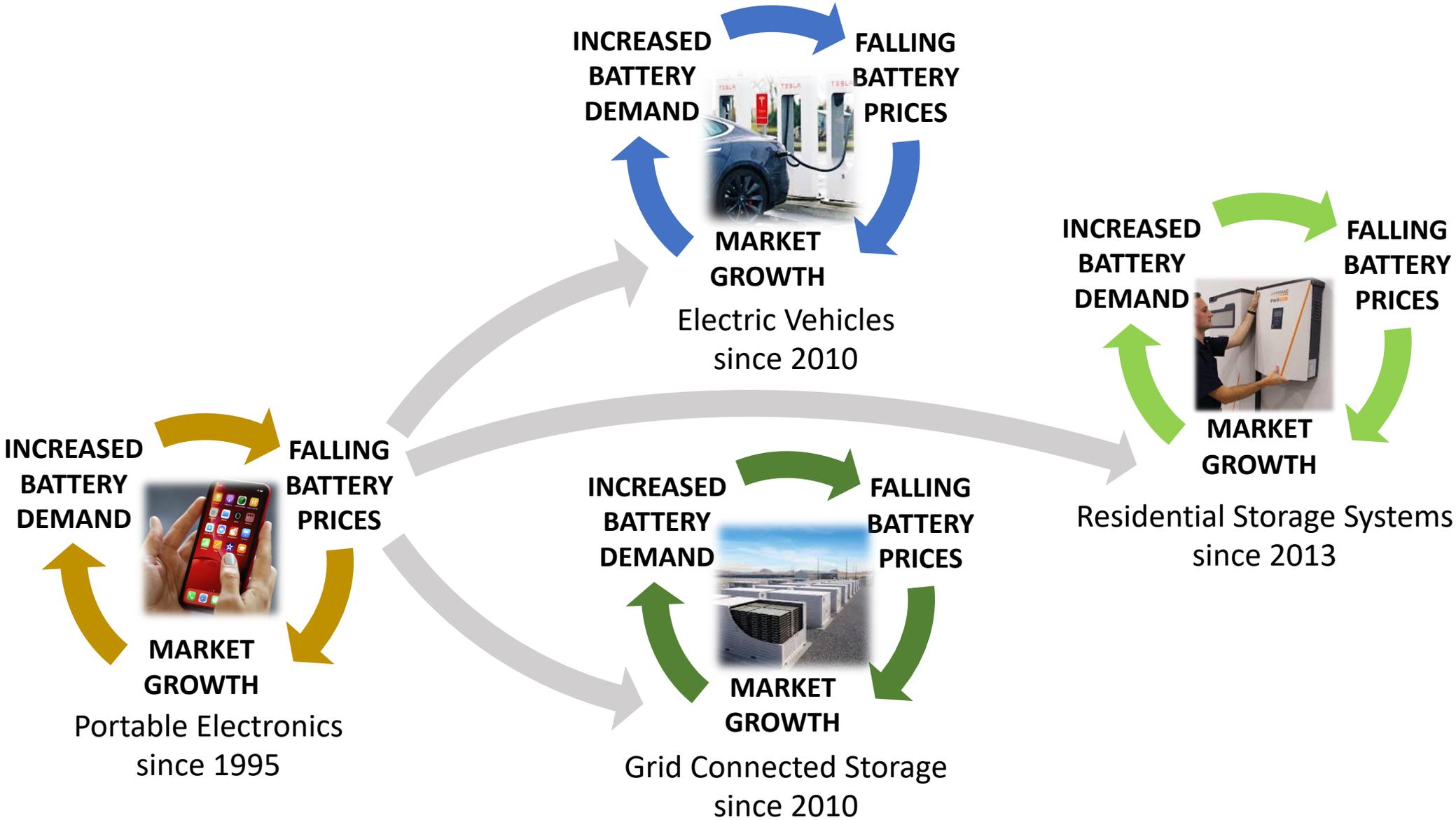
When we manufacture more and more of something, we get better at it.

Engineers and economists have studied and quantified this learning phenomenon.

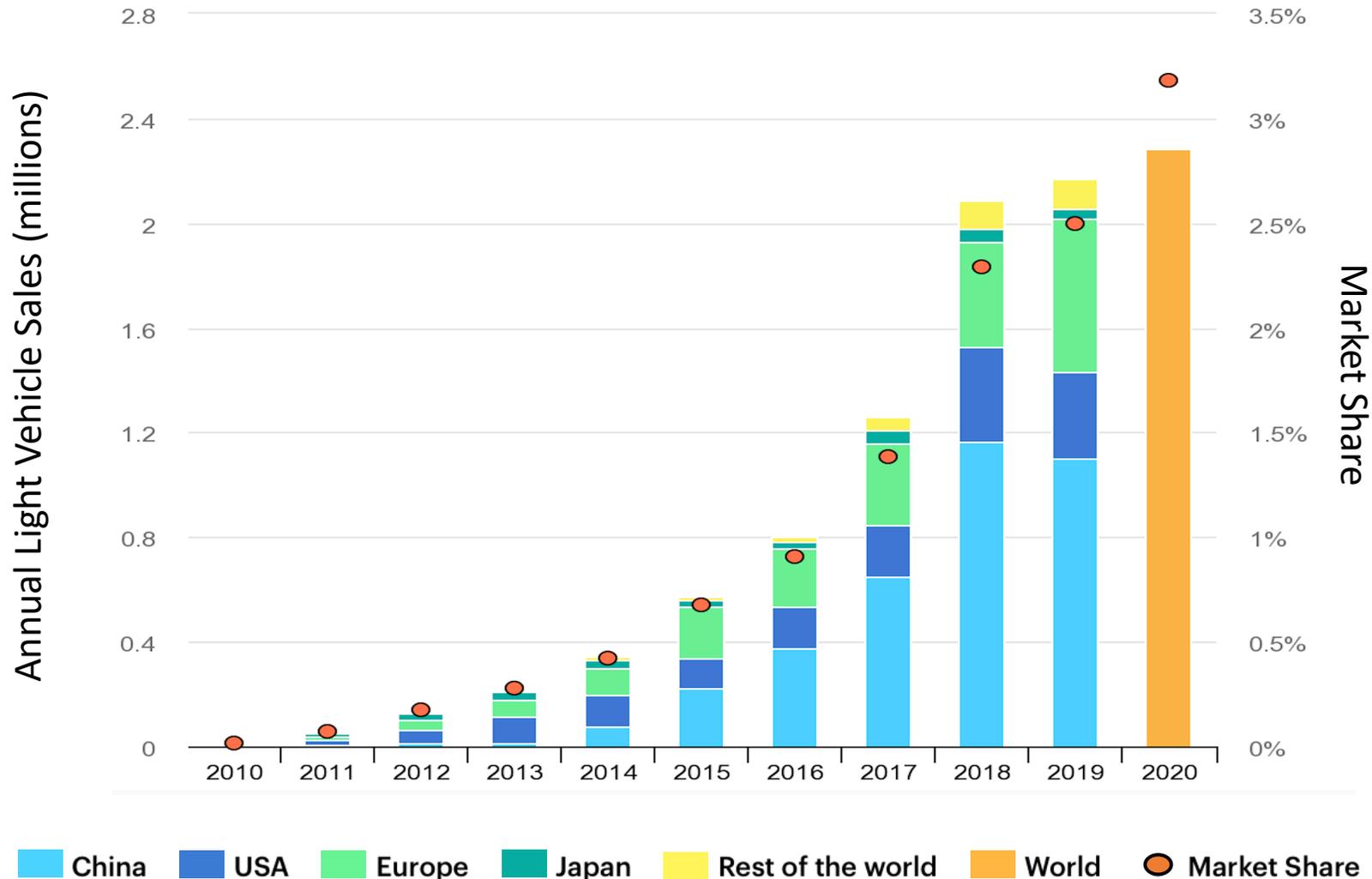
*We can confidently predict continued rapid cost reductions,
so long as manufacturing volumes continue to rapidly increase.*

(For much more on this subject, search "Wright's Law" or "the experience curve".)

Falling battery prices have enabled new products and applications.



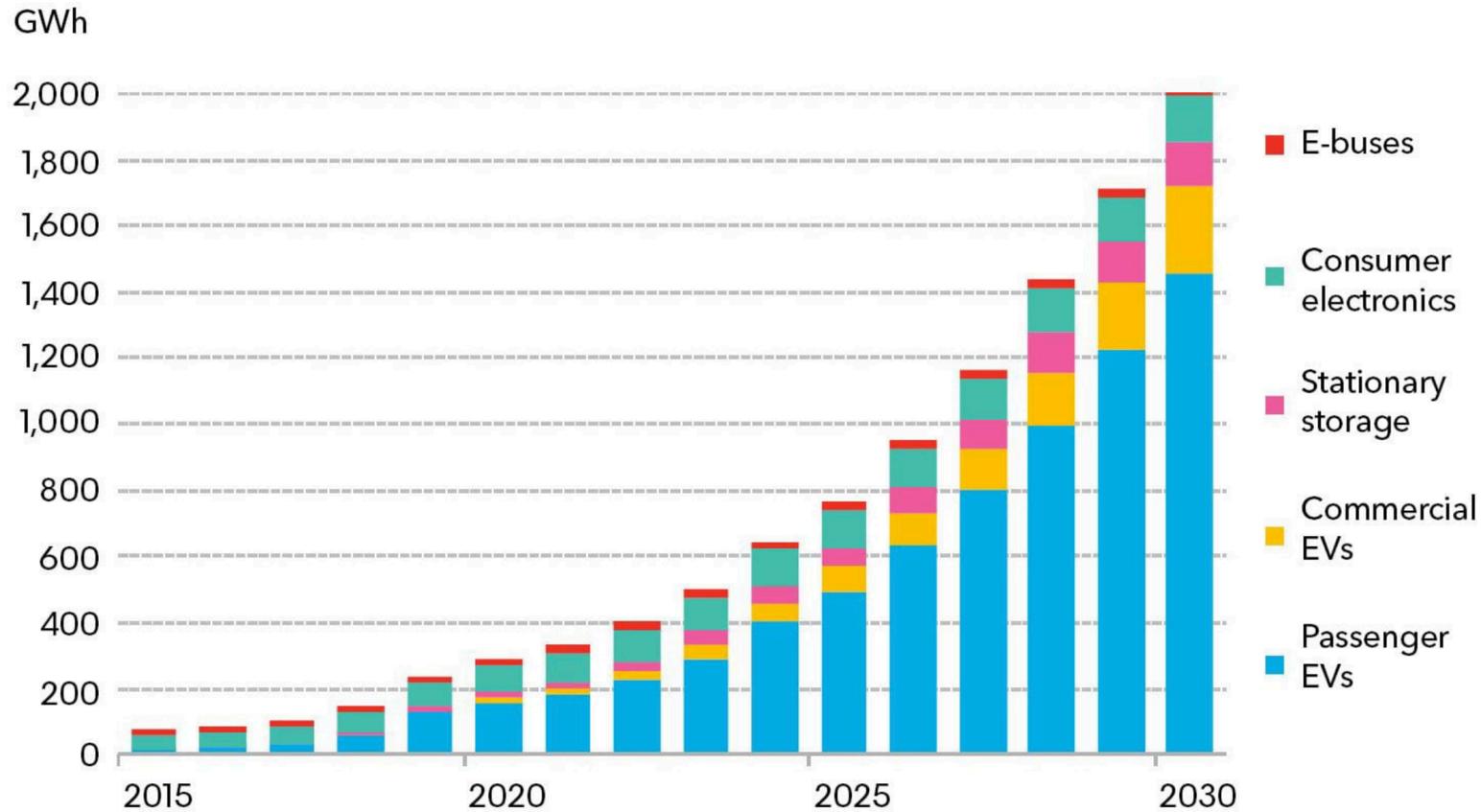
Electric vehicle (EV) sales are growing very rapidly...



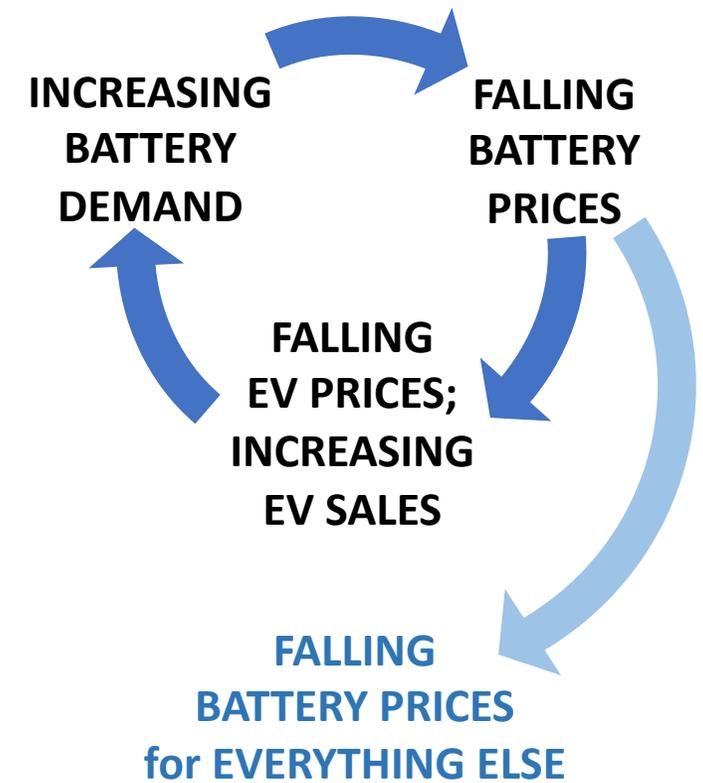
Source: [International Energy Agency](#)

... and already dominate global battery demand.

Annual lithium-ion battery demand



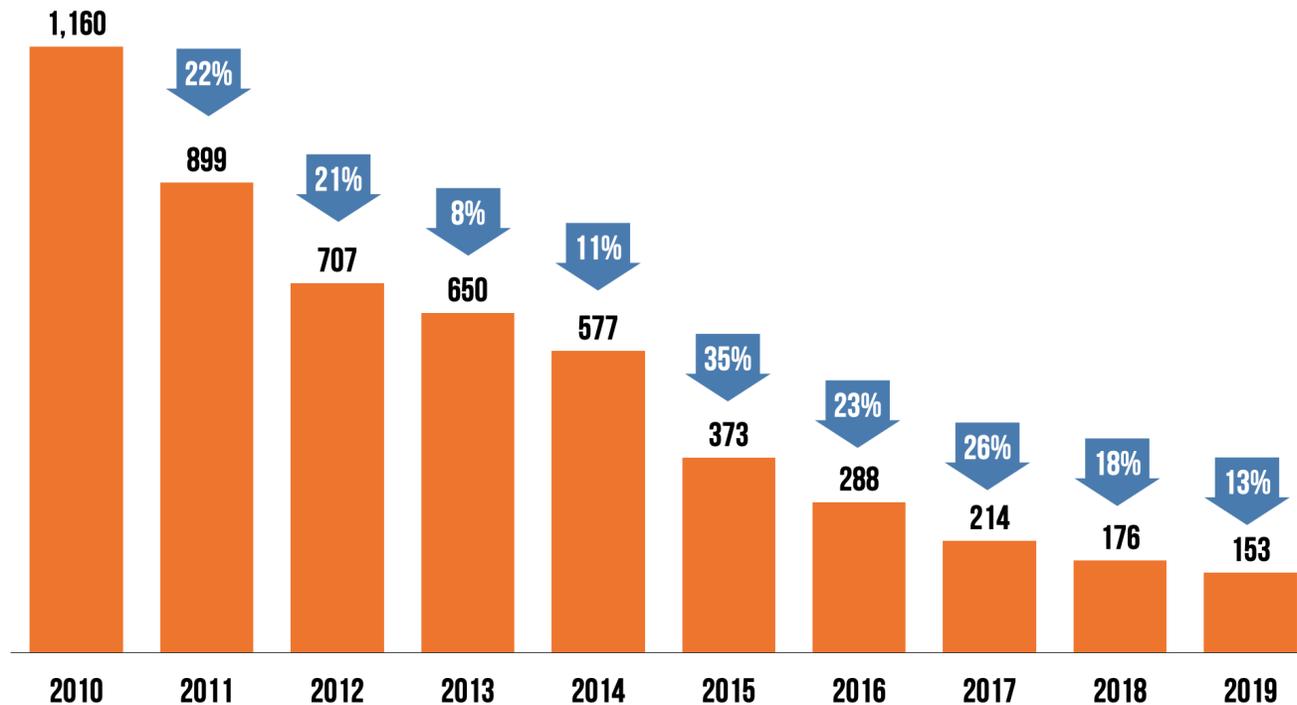
Source: BloombergNEF, Avicenne



Because manufacturing volumes have rapidly increased, battery pack prices have rapidly fallen.

PRICE OF A LI-ION BATTERY PACK, VOLUME-WEIGHTED AVERAGE

Real 2018 dollars per kilowatt hour



PREDICTIONS:

Prices will continue to fall.

Batteries will continue to improve.

New applications will continue to emerge.

Source: BloombergNEF



Coming next: trucks



Source: [CleanTechnica](#)
Image Credit: Ford

Coming Soon: Battery Electric Ships and Planes

Vigor Shipyards Chooses ABB Battery Electric Power For New Ferries In Washington

Source: [Clean Technica](#)



Image Source: Vigor

The world's largest electric plane just took its first flight.

Source: [Business Insider](#)



Image Source: MagniX

Wait! Won't there be a shortage of lithium?

Not in the long term!

- Comparable in abundance to copper, chromium, zinc, and nickel – all currently mined in far greater quantities than lithium
- Found on all continents in concentrations suitable for mineral extraction

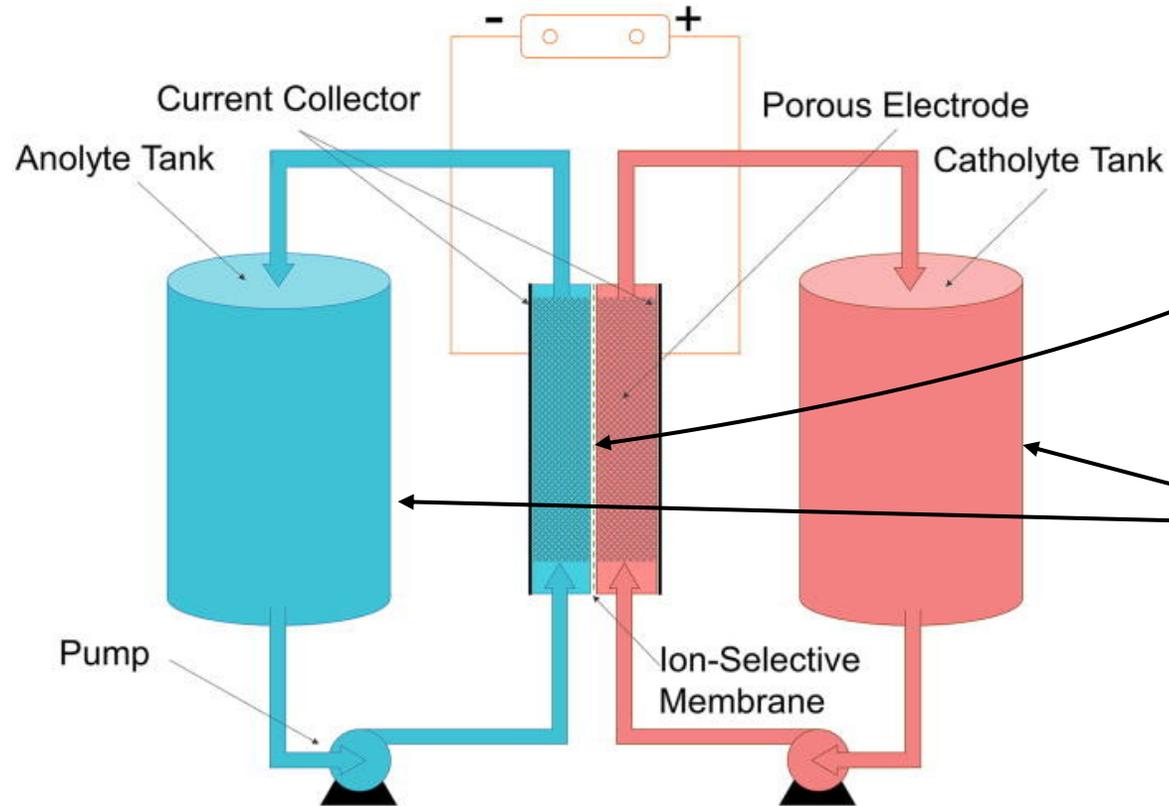
As electric transportation matures, recycling will limit the demand for newly-mined battery materials such as lithium, nickel, and cobalt.

- *JB Straubel's Redwood aims to extract lithium, cobalt and nickel from old smartphones*
[Financial Times, September 17, 2020](#)
- *Li-Cycle To Build Li-ion Battery Recycling Hub In Rochester, New York*
[INSIDEEVs, September 18, 2020](#)

What's Next?

Emerging Technologies for Longer-term Energy Storage

Flow Batteries



Power and Energy Capacities can be independently adjusted.

Power: increase or decrease area of ion-selective membrane

Energy: increase or decrease volume of storage tanks

Source: Wikipedia

Cryogenic Energy Storage (Highview Power)



The CRYOBattery is reportedly coming to the U.S.

Image: Highview Power

Gravitational Energy Storage

Energy Vault (conceptual image)



Image Credit: [Energy Vault](#)

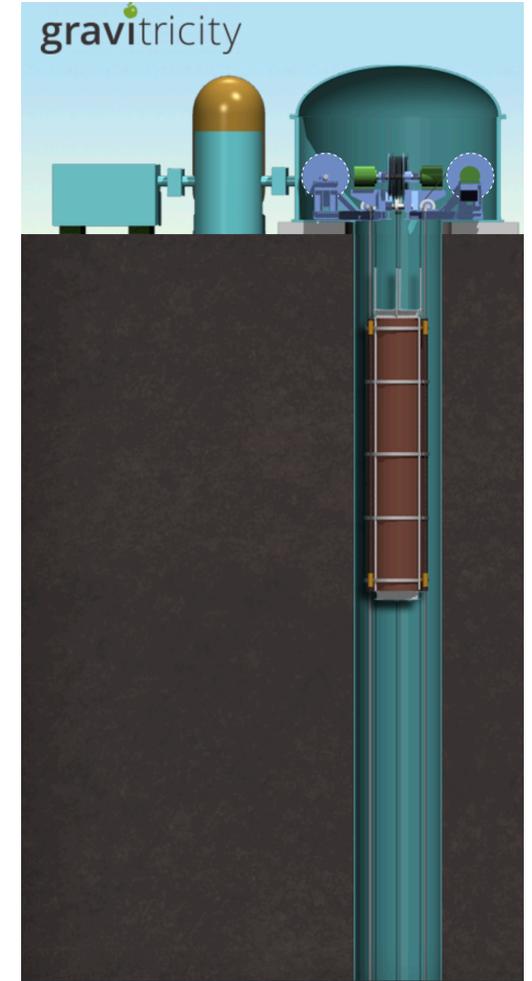
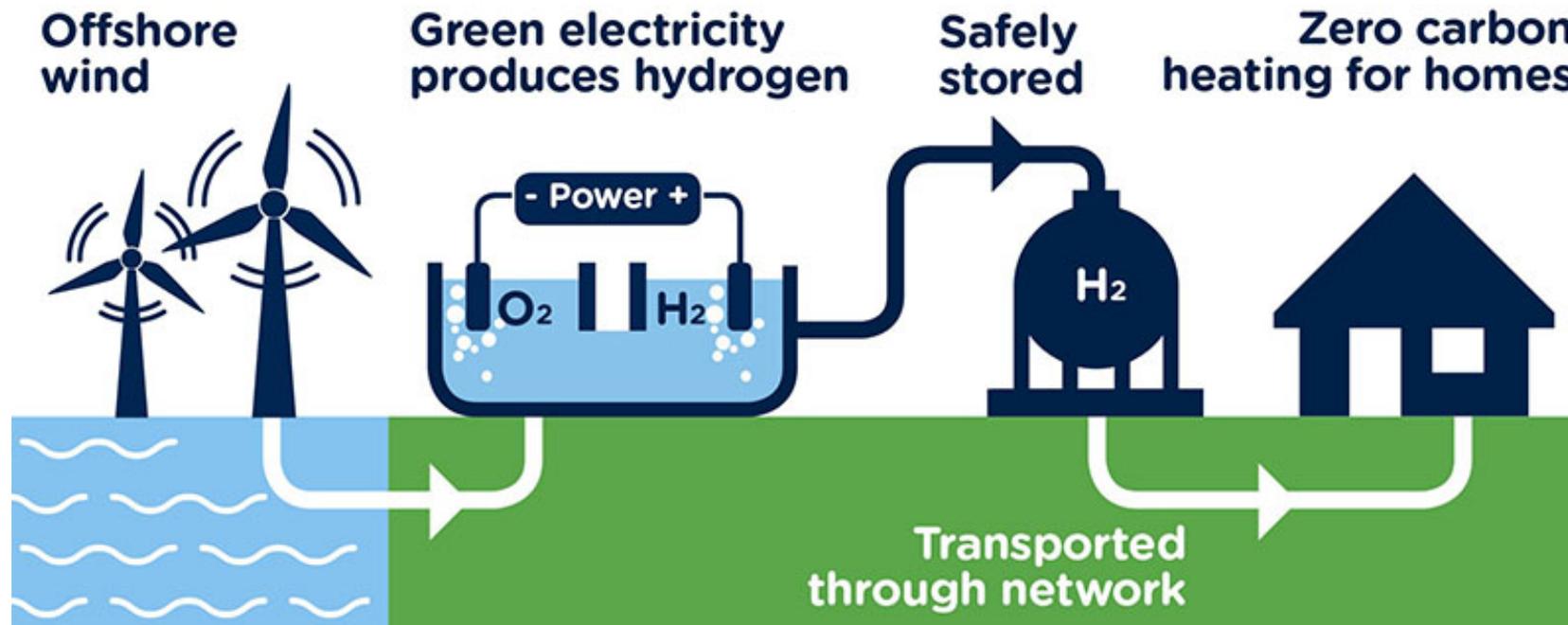


Image Credit: [Gravitricity](#)

Green Hydrogen

- Use solar or wind energy to break water into its components, hydrogen and oxygen.
- Store the hydrogen in tanks or pipe it to where energy is needed.
- Burn the hydrogen to create heat for industrial processes that are otherwise difficult to electrify.
- The exhaust is water vapor (zero net carbon, no particulates)!



Green Hydrogen for Industrial Processes

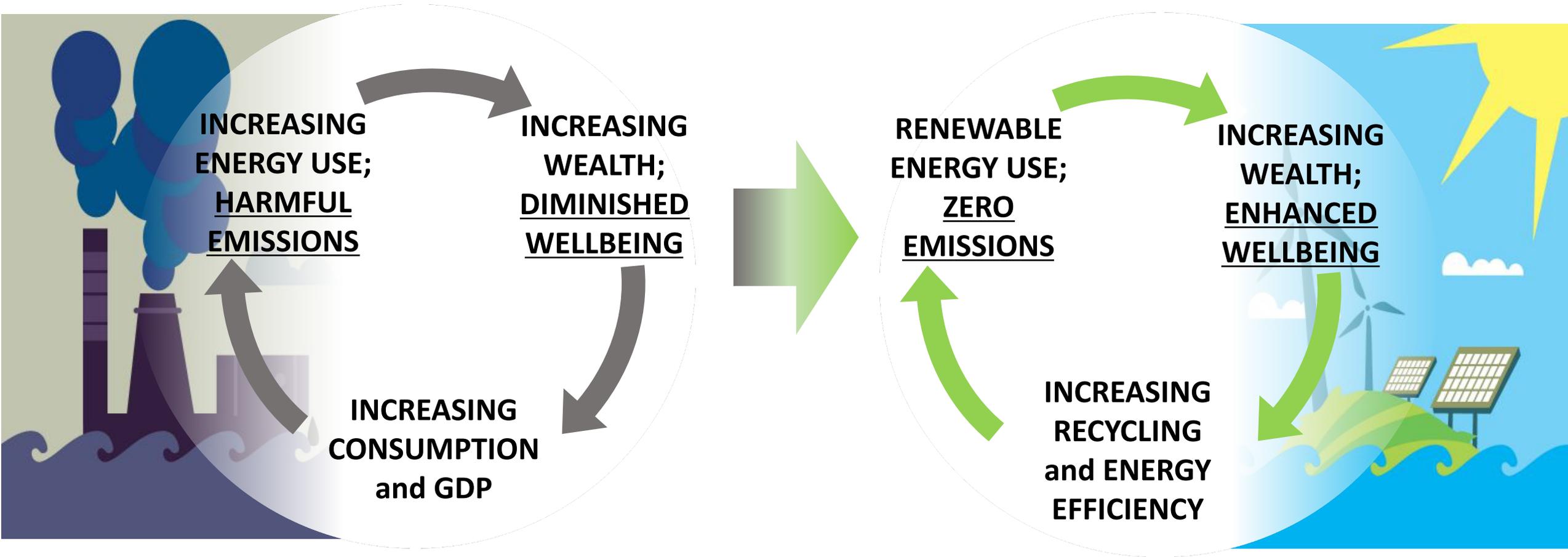
August 1, 2020:
The world's first fossil-free
hydrogen-powered steel
plant began operations in
Sweden.

Steel from green hydrogen
exemplifies the potential
of our ongoing transition
to renewable energy.



Source: [h2-view.com](https://www.h2-view.com)

The Renewable Energy Transition: Replacing Fossil Fuels *Throughout* the Economy



Keep these developments in perspective.

A zero net carbon economy is still decades away.

Except for pumped hydro, most announcements about long-term energy storage concern demonstration projects.

98% of ongoing commercial investment goes to lithium-ion batteries!

Prediction: Commercial investment will shift to longer duration energy storage after lithium ion battery technology has saturated the market for shorter duration (less than 8-hour) storage.

Summing Up

The lithium-ion battery was the product of forward-looking applied research in industry and academia.

Over decades, competitive markets drove continuous incremental improvement, cost reduction, and rapidly expanding applications.

Today, battery energy storage is enabling our ongoing transition to renewable energy.

A brighter future is coming.

**Your personal decisions and community
engagement help to accelerate the transition.**

Thanks!

The Holy Name of Mary Care for Creation website:

<https://www.hnmcare4creationministry.com>

Back-up Material for Possible Use in Q&A

To learn more ...

How a Wind Turbine Works

Animation from Wind Energy Association

<https://www.energy.gov/eere/wind/animation-how-wind-turbine-works>

How a Solar Cell Works

5-minute YouTube Video from Brown University

<https://www.youtube.com/watch?v=UJ8XW9AgUrw>

How a Lithium-ion Battery Works

Scientific Background on the Nobel Prize in Chemistry 2019 LITHIUM-ION BATTERIES; Royal Swedish Academy of Sciences

<https://www.nobelprize.org/uploads/2019/10/advanced-chemistryprize2019.pdf>

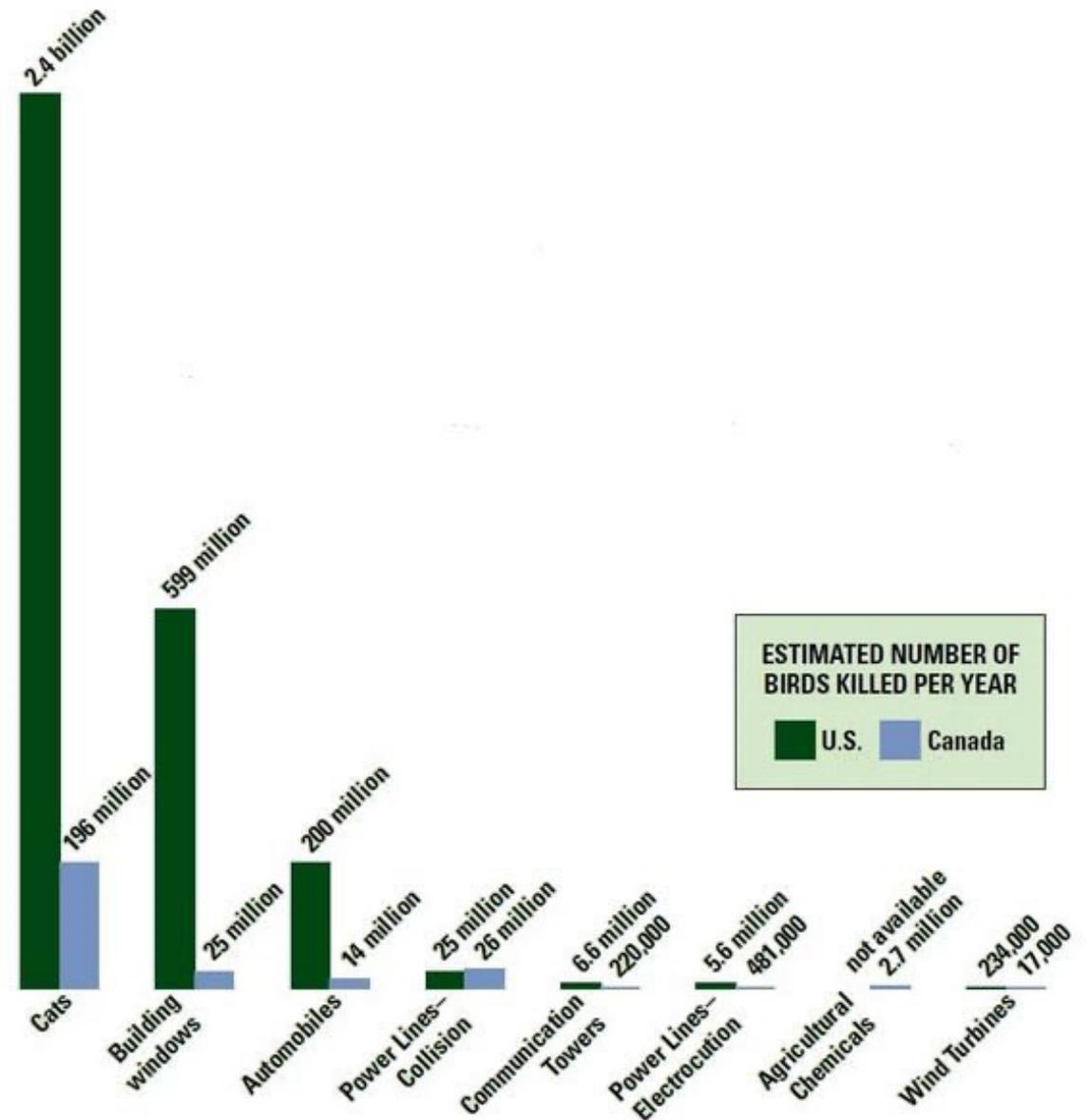
Wind turbines are *not* a leading cause of bird deaths.

Habitat destruction due to agriculture, deforestation, and urbanization is by far the greatest cause of bird population declines.

Additional drivers are shown in the graph at right, from [The State of the Birds 2014](#) report of the U.S North American Bird Conservation Initiative.

Climate Change

About two-thirds of America's birds will be threatened with extinction if global warming rises by 5.4 degrees Fahrenheit by 2100, according to a [report released](#) by the National Audubon Society.



Are Electric Vehicles Truly “Green”?

Everything we currently manufacture has a carbon cost, but recent studies show the lifetime carbon cost of building and operating an electric vehicle is *much* less than that of an internal combustion engine vehicle. https://www.oliver-krischer.eu/wp-content/uploads/2020/08/English_Studie.pdf

Five reasons *some* earlier studies came to more pessimistic conclusions:

- 1. Exaggerate GHG emissions of battery production**
Economies of scale and smarter engineering have dramatically lowered the energy that factories require to produce battery cells. At the same time the electricity used is steadily decarbonizing.
- 2. Underestimate battery lifetime**
Empirical data shows modern batteries will most probably last for more than 300,000 miles. New studies claim over 1 million miles is possible with current technology.
- 3. Assume electricity will not get cleaner over the lifetime of the car**
Just as the electricity mix has changed dramatically over the past 20 years, it will change over the next 20 years.
- 4. Use laboratory tests paid for by manufacturers themselves**
Instead, use CO₂ emissions from independent empirical measurements.
- 5. Exclude or downplay fuel production emissions** New research into well-head flaring and other sources of GHG emissions shows that the emissions related to the production of gasoline and diesel are larger than previously thought. To account for the production of fuel, cars driving on gasoline should add 30% to their tailpipe emissions.

How quickly might electric vehicles replace combustion engine vehicles?

5th Avenue, NYC, Easter Morning, 1900



Source: [National Archives Catalog](#)

5th Avenue, NYC, Easter Morning 1911



Source: [George Grantham Bain Collection, Library of Congress](#)

Lithium is not rare. Battery prices have dropped even as lithium prices have fluctuated.

Benchmark Lithium Price

Average Battery Price

