THE WORLD'S LEADING RESOURCE FOR CLIMATE SOLUTIONS

Our mission is to help the world reach "Drawdown"— the point in the future when levels of greenhouse gases in the atmosphere stop climbing and start to steadily decline, thereby stopping catastrophic climate change — as quickly, safely, and equitably as possible.

Our latest publication

"Farming Our Way Out

CLIMATE SOLUTIONS BY SECTOR

Within each of these sectors are solutions to climate change with actions that can be taken today.

ELECTRICITY

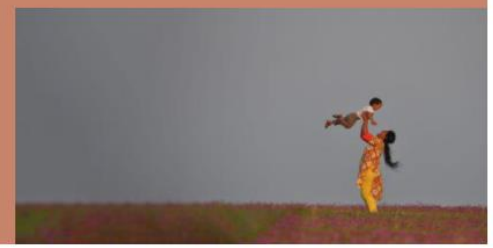
FOOD, AGRICULTURE, AND LAND USE

INDUSTRY

TRANSPORTATION

BUILDINGS

HEALTH AND EDUCATION



LAND SINKS

COASTAL AND OCEAN SINKS

ENGINEERED SINKS

Whether grid-connected or part of stand-alone systems, rooftop solar panels and other distributed solar photovoltaic systems offer hyper-local, clean electricity generation.

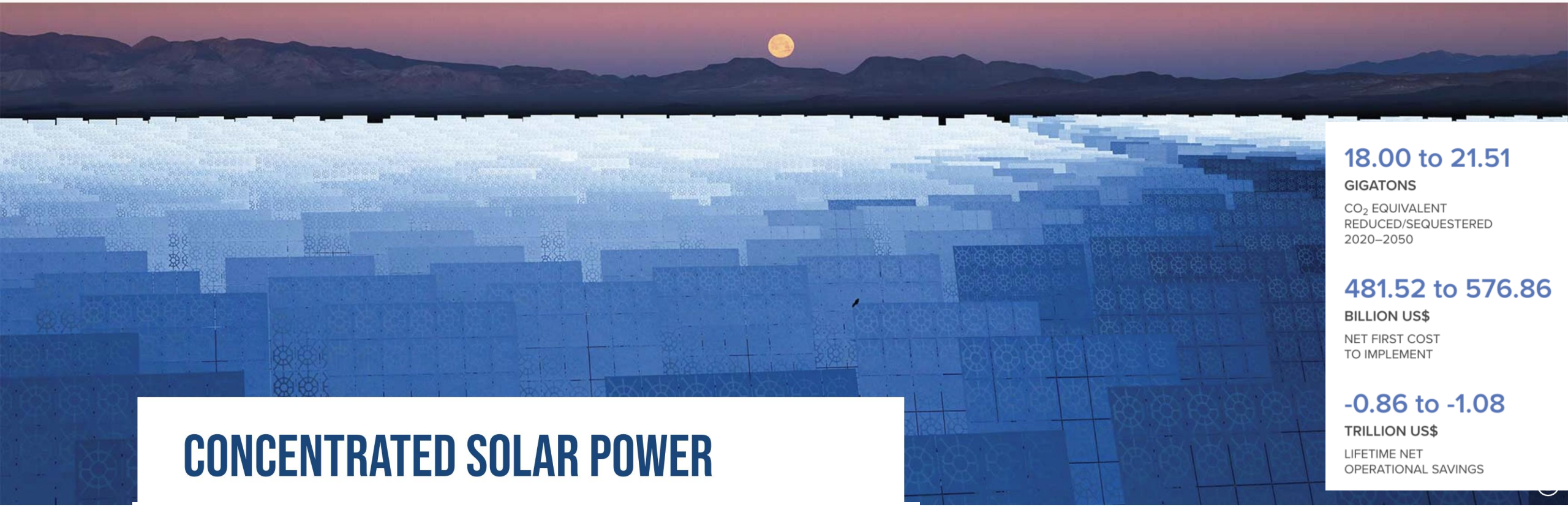
DISTRIBUTED SOLAR PHOTOVOLTAICS

Drawdown solution

drawdown.org/solutions/concentrated-solar-power

PROJECT DRAWDOWN

DONATE



18.00 to 21.51
GIGATONS
CO_2 EQUIVALENT REDUCED/SEQUESTERED 2020–2050

481.52 to 576.86
BILLION US$
NET FIRST COST TO IMPLEMENT

-0.86 to -1.08
TRILLION US$
LIFETIME NET OPERATIONAL SAVINGS

CONCENTRATED SOLAR POWER

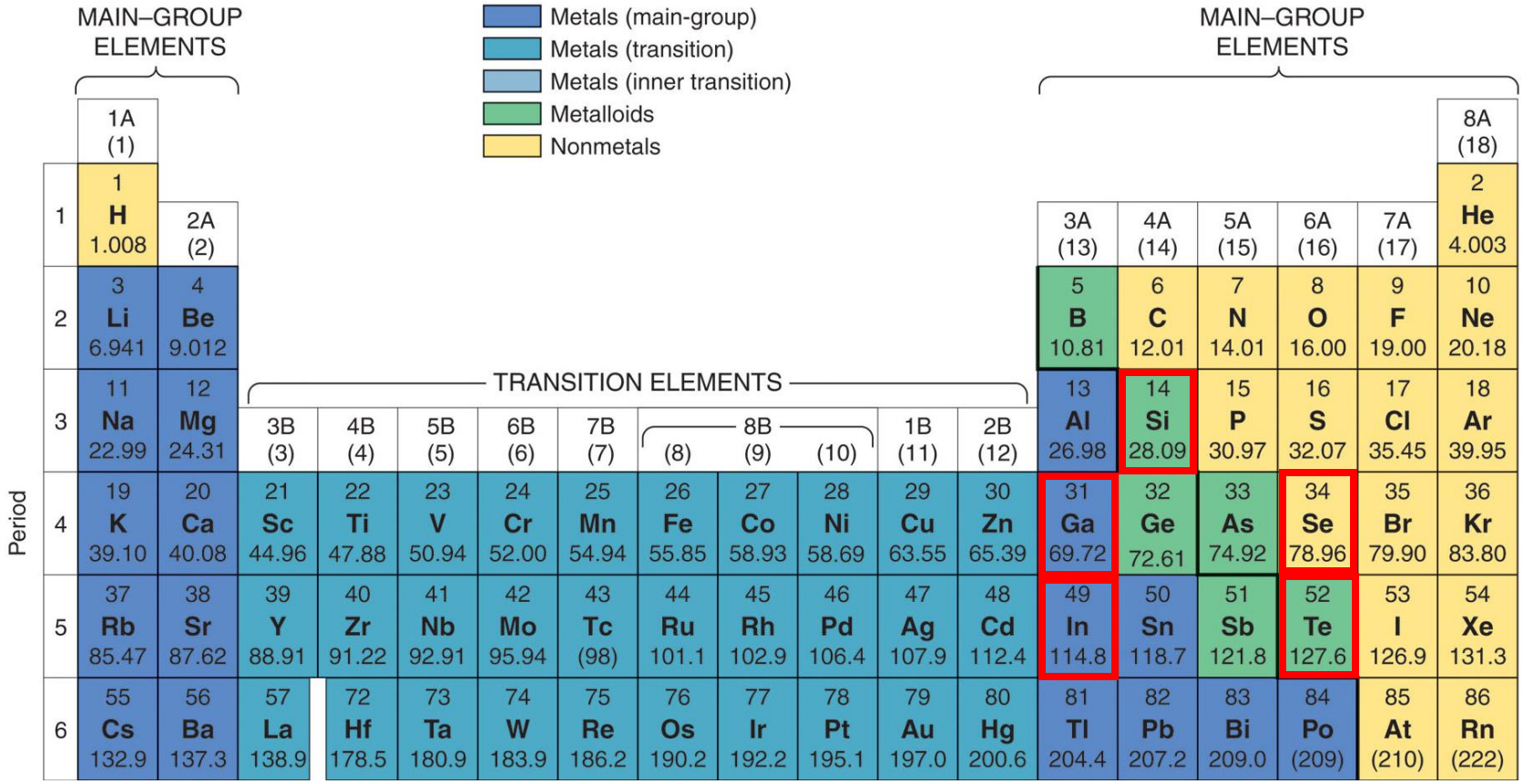
Concentrated solar power uses sunlight as a heat source. Arrays of mirrors concentrate incoming rays onto a receiver to heat fluid, produce steam, and turn turbines.

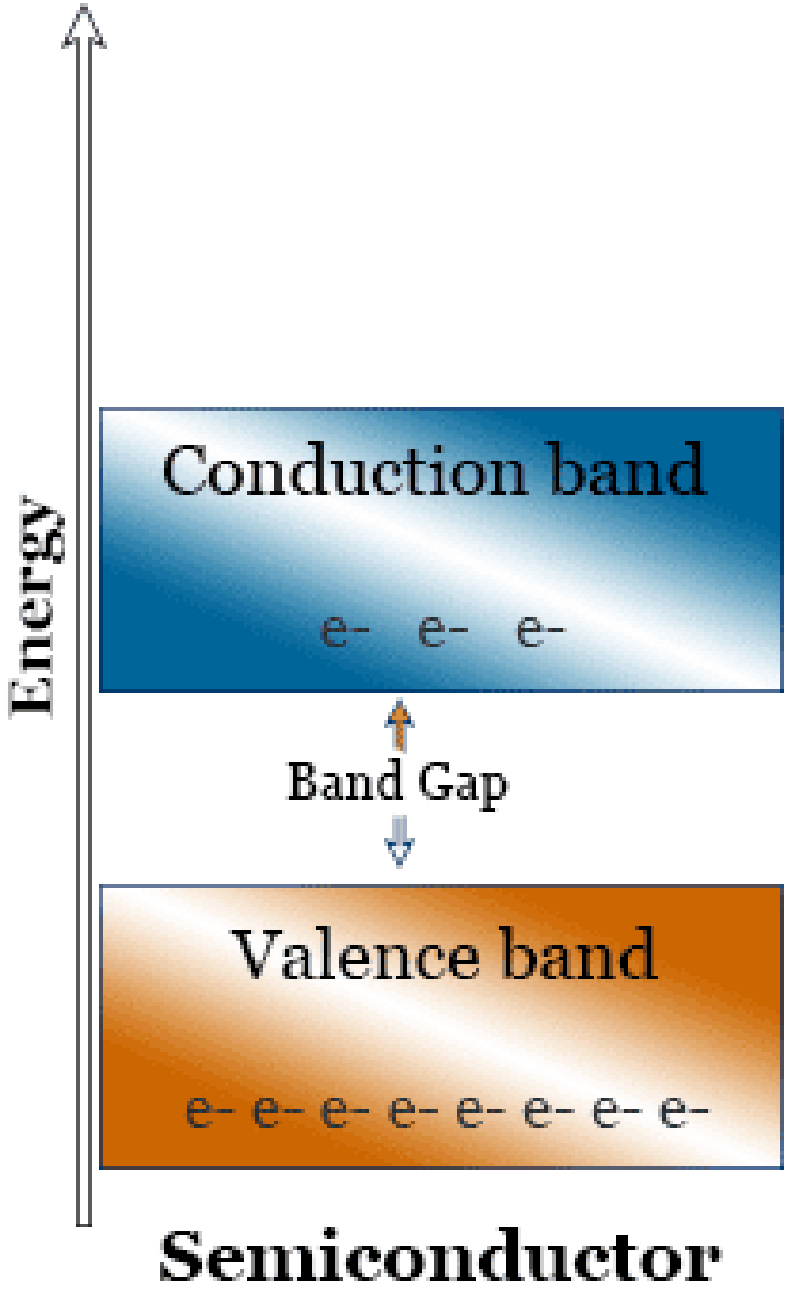
Drawdown solution

Photovoltaic cells can be made of:

- Crystalline silicon
- Cadmium telluride (CdTe)
- Copper indium gallium diselenide (CIGS)

All Semiconductors

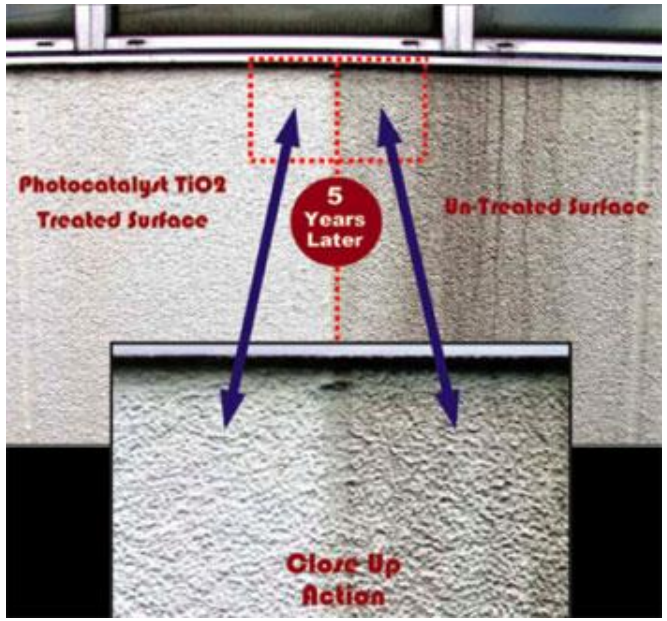




- Sunlight is absorbed by the semiconductor and promotes electrons from the valence band to the conduction band

- This charge separation allows for energy storage

Strange chemical properties of the semiconductor TiO_2



when exposed to light, TiO_2 interacts closely with water and repels compounds that don't mix well with water (soot, dust, oils)

$\Rightarrow$ "self-cleaning;" can efficiently cool buildings; anti-fog mirrors

TiO_2 chemical properties continued

When exposed to light, TiO_2 causes the chemical degradation (breakdown) of various pollutants. It also causes chemical reactions that kill bacteria.

$\Rightarrow$ Improve air quality

$\Rightarrow$ urinals that resist bacterial buildup (and self-clean too)

Credit: David Hofmann / Unsplash

RECYCLED METALS

Metals are extracted from nonrenewable ores. Recycled metals capitalize on already extracted materials—making it possible to produce goods more efficiently, reduce the need to extract new resources, and cut down on energy and water use.

Recycled metals are estimated to increase from 39 percent of the market to 41–48 percent of a growing market for metals production, saving 4.31–12.34 gigatons of carbon dioxide equivalent emissions between 2020 and 2050.

Drawdown solution

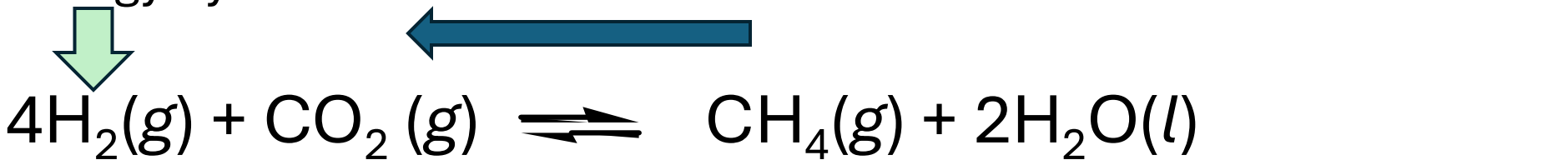
IMPROVED CATTLE FEED

Optimizing cattle feeding strategies can lower the methane emissions produced within the ruminant digestive system. Nutrient enriched diets of high-quality forages, additives, and supplements aim to improve animal health and productivity.

Drawdown solution

Chemistry in cows

- Methane (CH_4) is the second-most important greenhouse gas (not counting water vapor) → contributes 25-30% of anthropogenically caused global warming
- Cattle emit CH_4 formed in their gut…and contribute **27%** of all anthropogenic methane emissions!
- Methanogens = archea (single-celled microbes) living in the gut that get their energy by:



H_2 is produced with typical high-fiber grass and corn-byproduct diets…

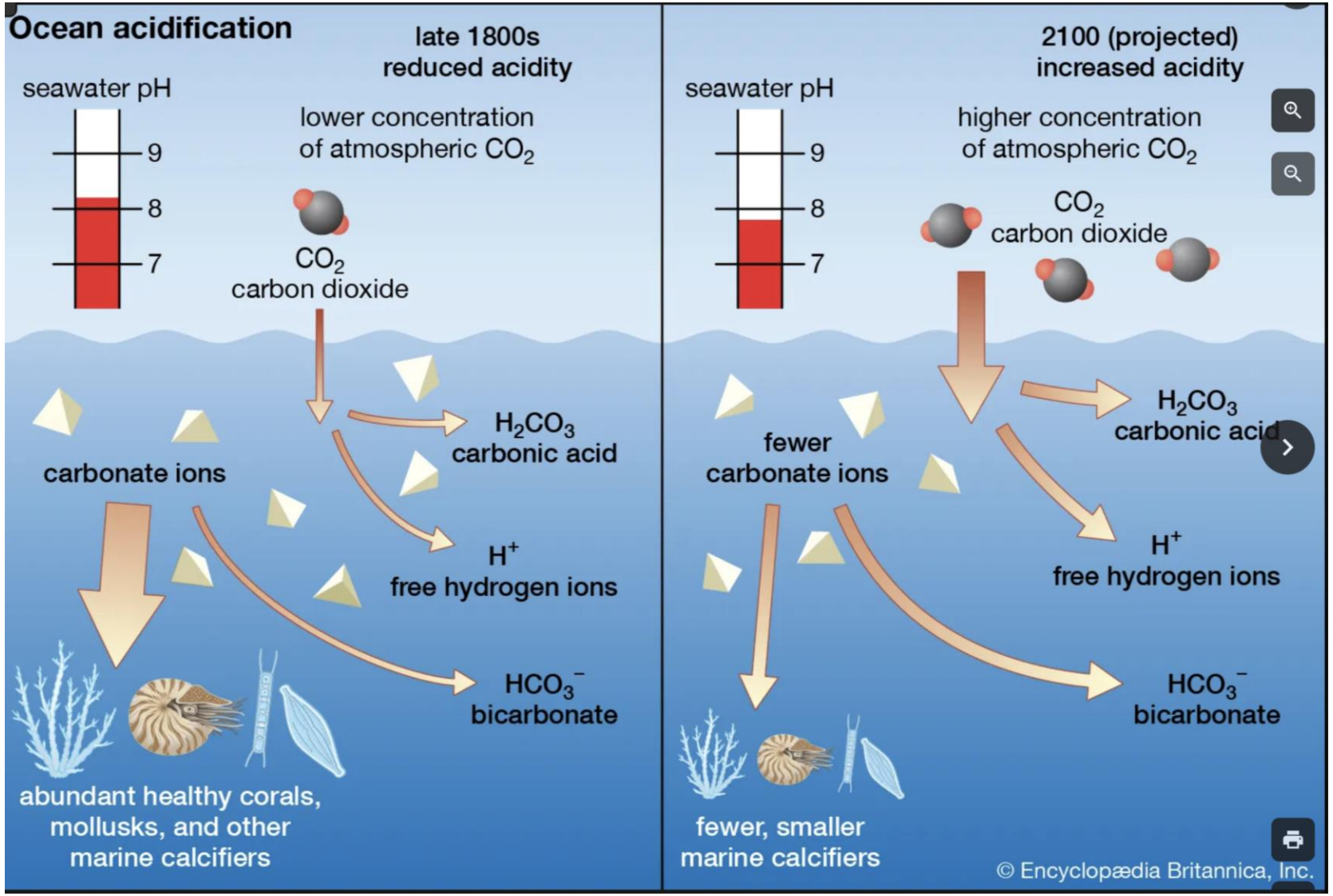
→

…but $H_2(g)$ is reduced by replacing portions of the diet with legumes, soy, corn…

→

Le Chatelier's Principle: shift reaction left, make less CH_4!

Ocean acidification and its effect on shelled organisms



$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

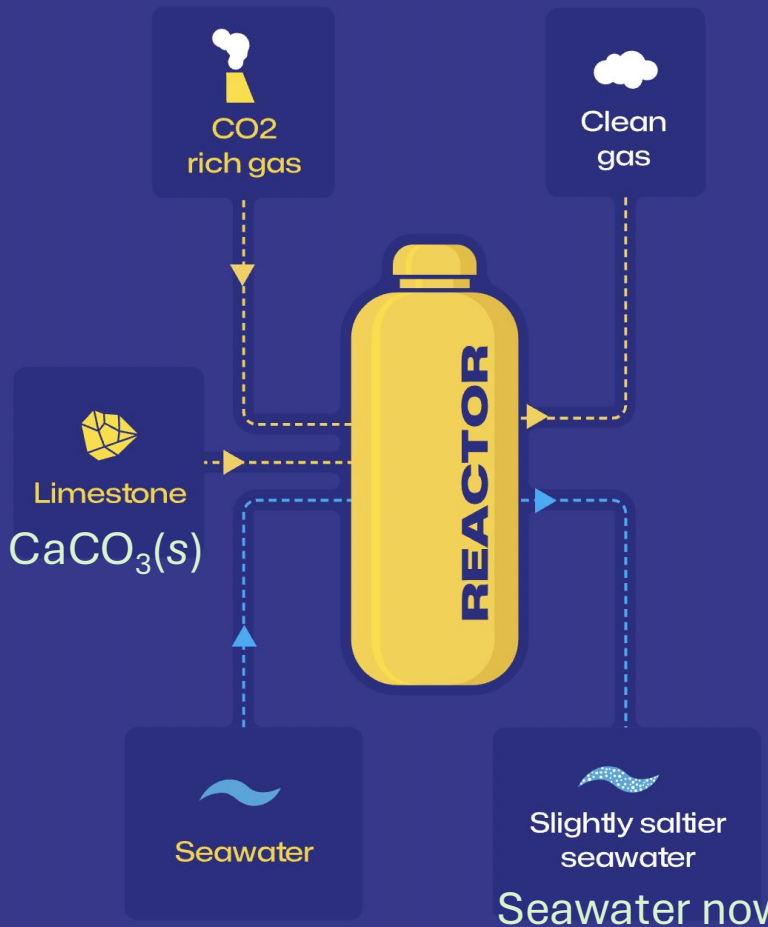
$$H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$$

Acid Base CB CA

$$CO_3^{2-} + H_3O^+ \rightleftharpoons HCO_3^- + H_2O$$

Base Acid CA CB

Direct CO_2 capture from ships...



Seawater now has more HCO_3^-

$CO_2 + H_2O \Leftrightarrow H_2CO_3$

$H_2CO_3 + H_2O \Leftrightarrow HCO_3^- + H_3O^+$

$CO_3^{2-} + H_3O^+ \Leftrightarrow HCO_3^- + H_2O$

OUR SOLUTION

Calcarea's technology helps reduce and remove carbon emissions by accelerating the Earth's natural carbon cycle

Based on over a decade of research in leading oceanography and marine engineering laboratories at Caltech and USC, our team has developed a reactor based on the "Accelerated Weathering of Limestone", which can be used to capture emissions from point sources and to safely store carbon captured from the atmosphere.

Calcarea's technology is smaller, more efficient, and lower cost than today's best available systems for Marine on-board carbon capture, and it eliminates the dependency on port infrastructure for handling of pure carbon dioxide.

Calcarea's system takes captured carbon dioxide and converts it into oceanic bicarbonate which is stable, secure, and environmentally benign.

← All the same reactions from the previous slide!!

EFFICIENT OCEAN SHIPPING

Huge volumes of goods are shipped across oceans. Fuel-saving ship design, technologies, and practices can trim greenhouse gas emissions.

A combination of 17 ship technologies with slow steaming (slowing the ship speed) can cut fuel consumption of ocean ships in half. If 50–75 percent of international ships adopt these technologies and practices, we could reduce carbon dioxide emissions 6.72–9.83 gigatons by 2050 at a net first cost to implement of US$0.72–1.01 trillion. That could save US$2.48–3.54 trillion in operating costs over the life of the ships.

Drawdown solution

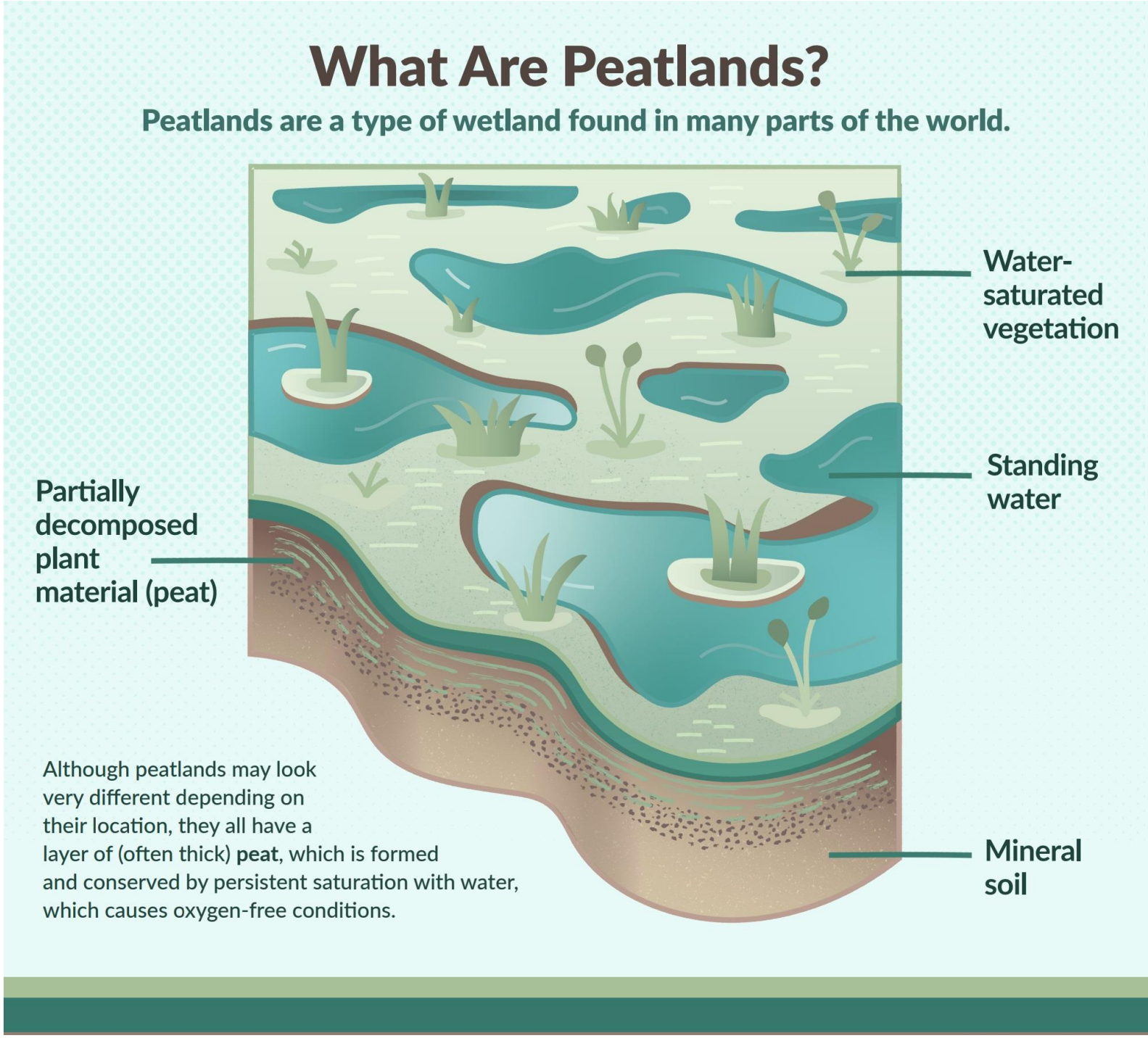
PEATLAND PROTECTION AND REWETTING

Peatlands hold vast amounts of carbon. Forestry, farming, fire, and fuel extraction release carbon and reduce peatlands' ability to store more. Protection and rewetting can reduce emissions while supporting peatlands' role as carbon sinks.

Drawdown solution

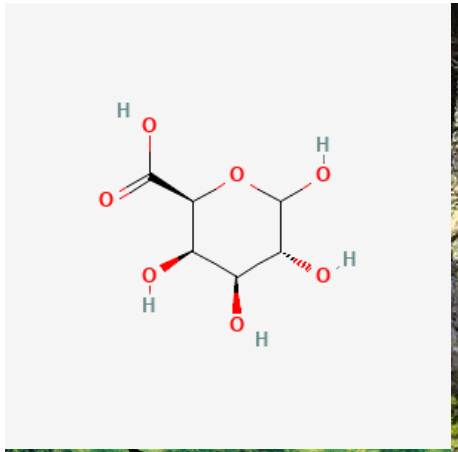
- Peat: dead and decomposing plant matter developed over centuries

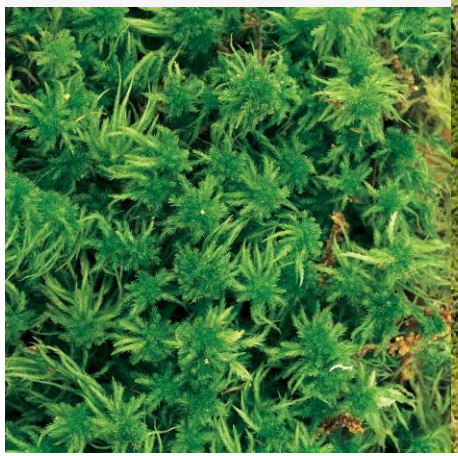
- Peatlands cover only 3% of Earth's land area but store 2x the carbon stored in the world's forests



- Sphagnum moss: produces galacturonic acid ($C_5O_5H_5COOH$), a weak acid that contributes to peatland water pH of <5

- Bacterial degradation of organic matter produces other weak organic acids (look for the –COOH group)





→ Peatlands can continue to sequester carbon **as long as they remain water-saturated** (decomposing matter stays as peat rather than going to CO_2 because there's no O_2 to react

Methane (or any!) Combustion is a Redox Reaction

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

ox #: -4 +1 0 +4 -2 +1 -2

→ O_2 is the oxidizing agent (for all combustion reactions)
→ CH_4 is the reducing agent

→ CH_4 is ~30x more powerful as a greenhouse gas than CO_2…so if it is produced, burn it up! (And use that for energy)

LANDFILL METHANE CAPTURE

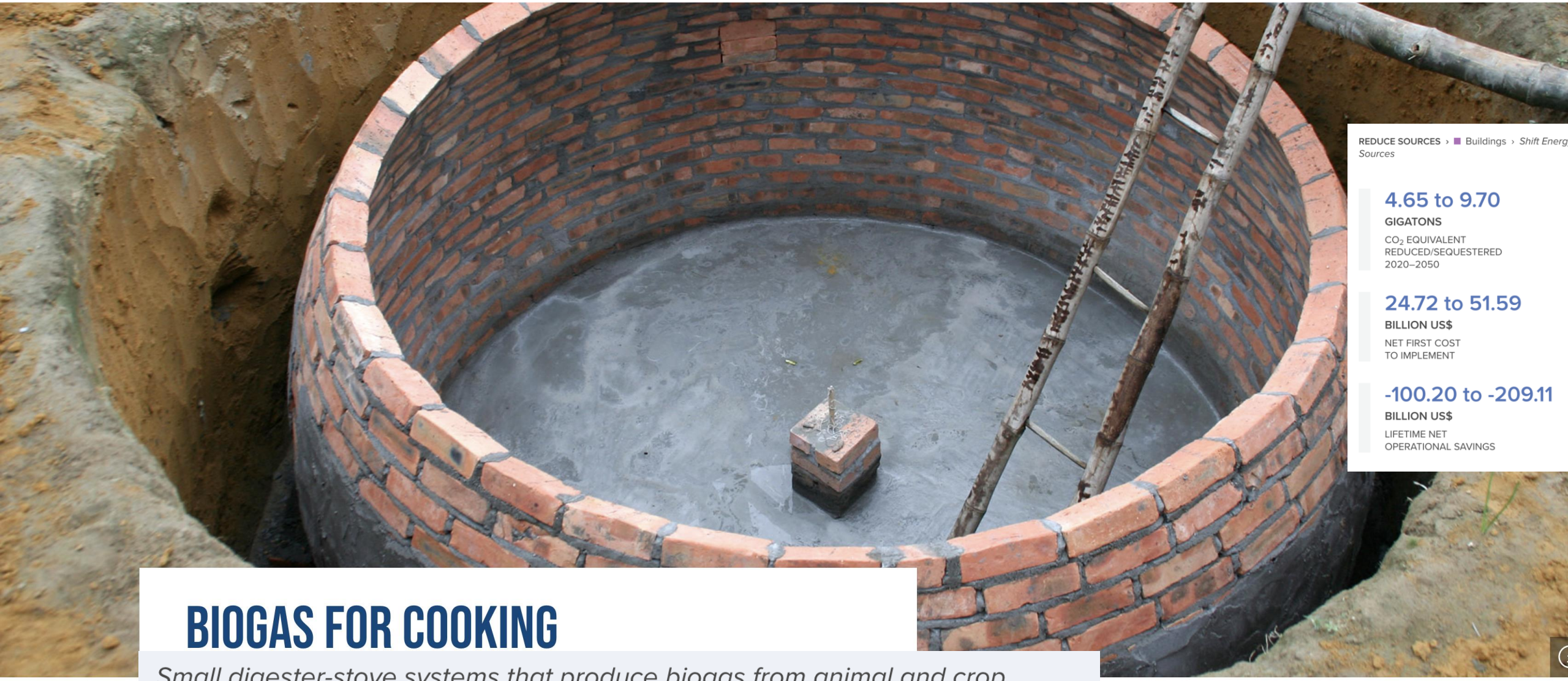
REDUCE SOURCES › Electricity › *Shift Production*
REDUCE SOURCES › Industry › *Use Waste*

-1.6–2.18
GIGATONS
CO2 EQUIVALENT
REDUCED / SEQUESTERED
(2020–2050)

$-4.31
BILLION $US
NET FIRST COST
(TO IMPLEMENT SOLUTION)

$-21.55–-6.89
BILLION $US
LIFETIME NET
OPERATIONAL SAVINGS

Drawdown solution



REDUCE SOURCES › ■ Buildings › *Shift Energ*
Sources

4.65 to 9.70
GIGATONS
CO_2 EQUIVALENT
REDUCED/SEQUESTERED
2020–2050

24.72 to 51.59
BILLION US$
NET FIRST COST
TO IMPLEMENT

-100.20 to -209.11
BILLION US$
LIFETIME NET
OPERATIONAL SAVINGS

BIOGAS FOR COOKING

Small digester-stove systems that produce biogas from animal and crop wastes make it possible to cook with biogas instead of wood and charcoal, which have adverse health and environmental consequences. We project that by 2050, such systems can replace 57–87 million cookstoves in Asia and Africa, avoiding 4.65–9.70 gigatons of carbon dioxide equivalent

Drawdown solution

Credit: Kristian Bjornard

METHANE DIGESTERS

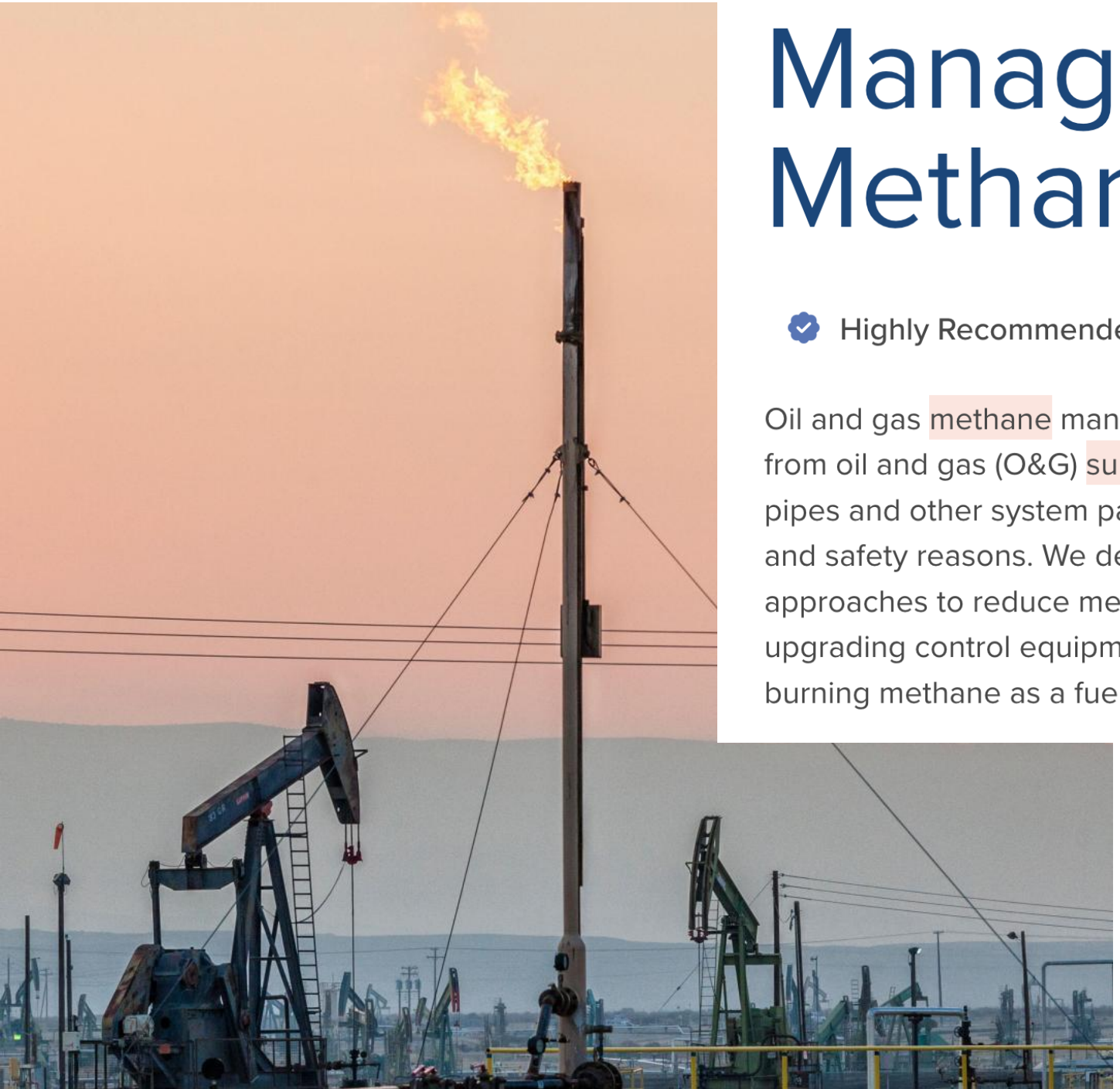
REDUCE SOURCES › Electricity › *Shift Production*
REDUCE SOURCES › Industry › *Use Waste*

6.18–9.83
GIGATONS
CO_2 EQUIVALENT
REDUCED / SEQUESTERED
(2020–2050)

$173.4–284.78
BILLION $US
NET FIRST COST
(TO IMPLEMENT SOLUTION)

$-2.83–-1.63
BILLION $US
LIFETIME NET
OPERATIONAL SAVINGS

Drawdown solution



Manage Oil & Gas Methane

Highly Recommended

Oil and gas methane management is the process of reducing methane emissions from oil and gas (O&G) supply chains. These supply chains release methane when pipes and other system parts leak or methane is intentionally vented for operation and safety reasons. We define the Manage Oil & Gas Methane solution as adopting approaches to reduce methane emissions, including fixing leaks in components, upgrading control equipment, changing procedures, and destroying methane by burning methane as a fuel or in flares.

Drawdown solution

Standalone batteries and electric vehicles store energy. They can enable 24/7 electricity supply even when the sun isn't shining or the wind isn't blowing.

Credit: Hannah Peters

DISTRIBUTED ENERGY STORAGE

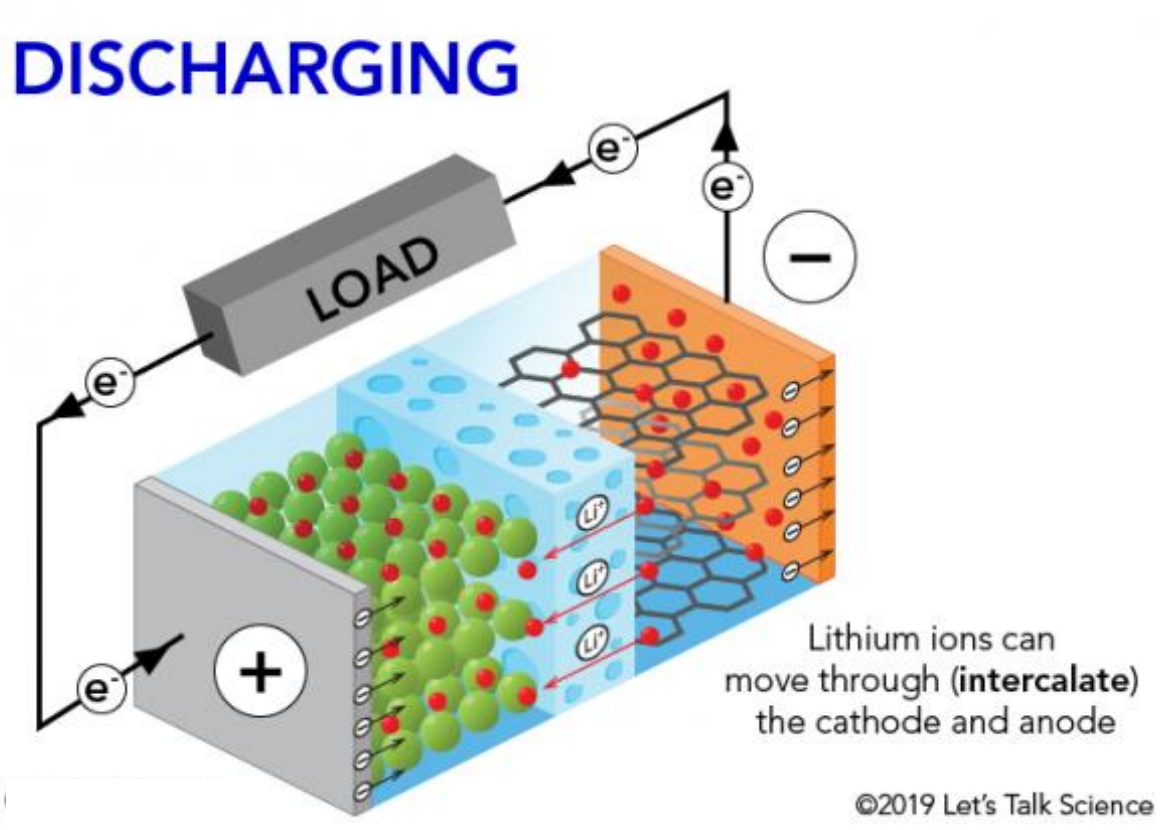
Distributed energy storage is an essential enabling technology for many solutions. Microgrids, net zero buildings, grid flexibility, and rooftop solar all depend on or are amplified by the use of dispersed storage systems, which facilitate uptake of renewable energy and avert the expansion of coal, oil, and gas electricity generation. Adoption of distributed storage is different for urban and rural settings. The greenhouse gas and financial impacts of the Distributed Energy Storage solution are accounted for by other drawdown solutions, so we don't quantify them here.

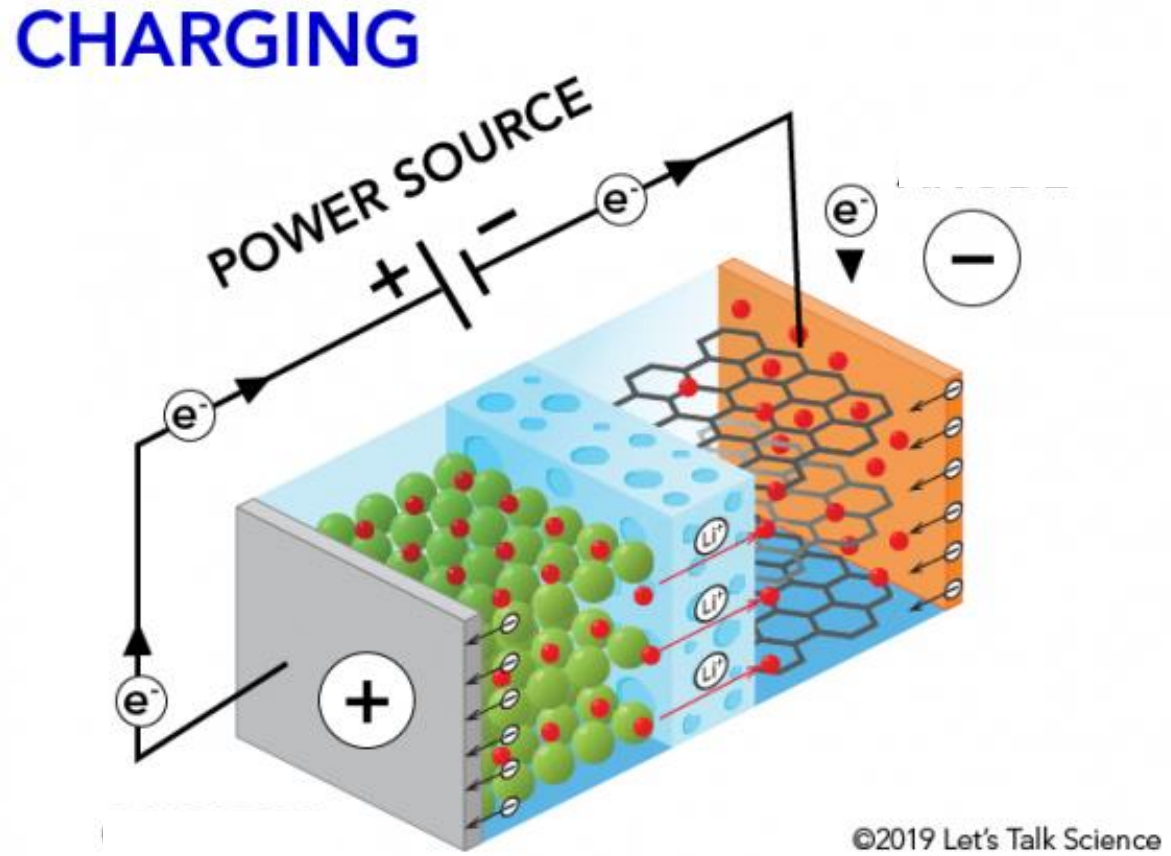
Drawdown solution

Lithium ion batteries

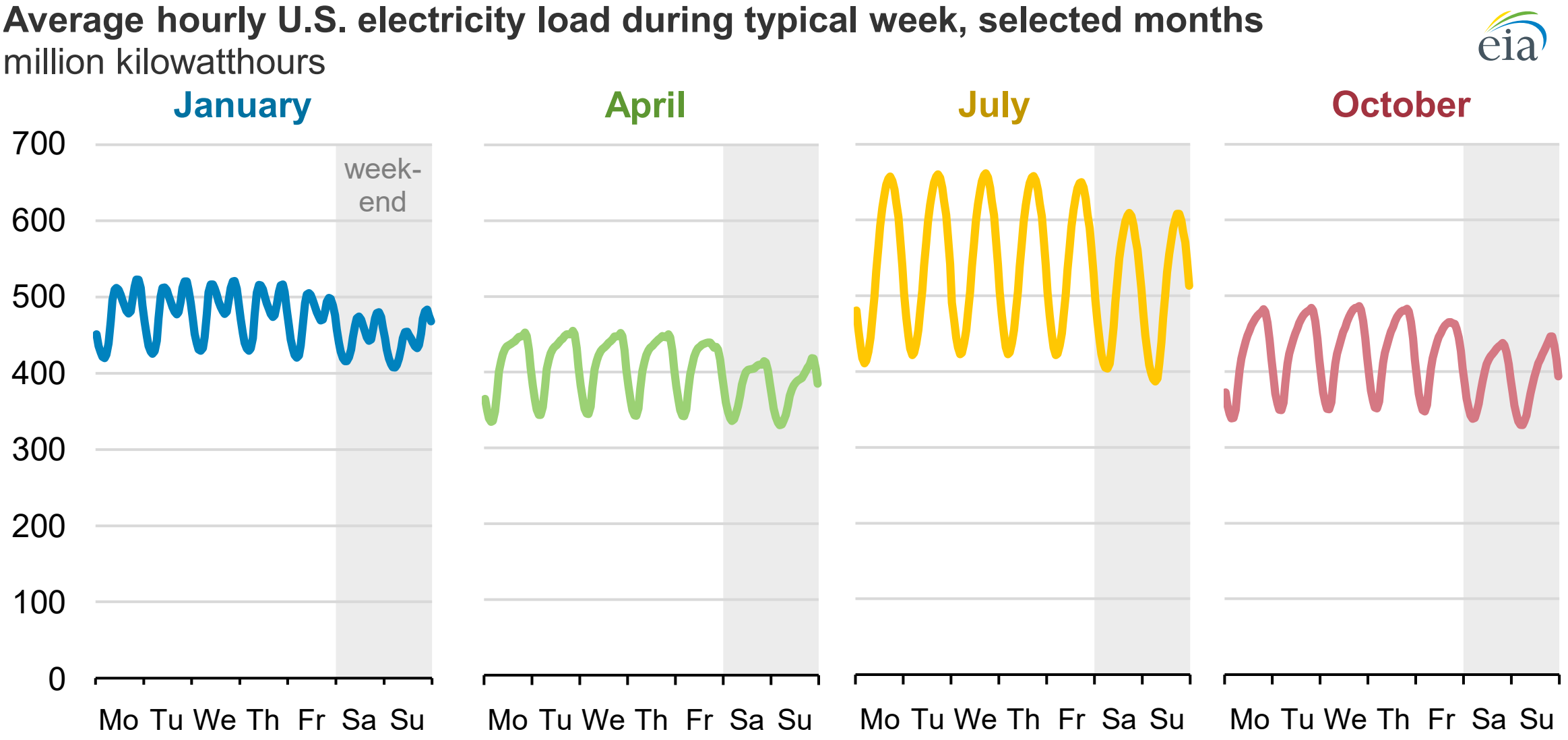
$LiC_6 \longleftrightarrow C_6(s) + Li^+ + e\text{-}$

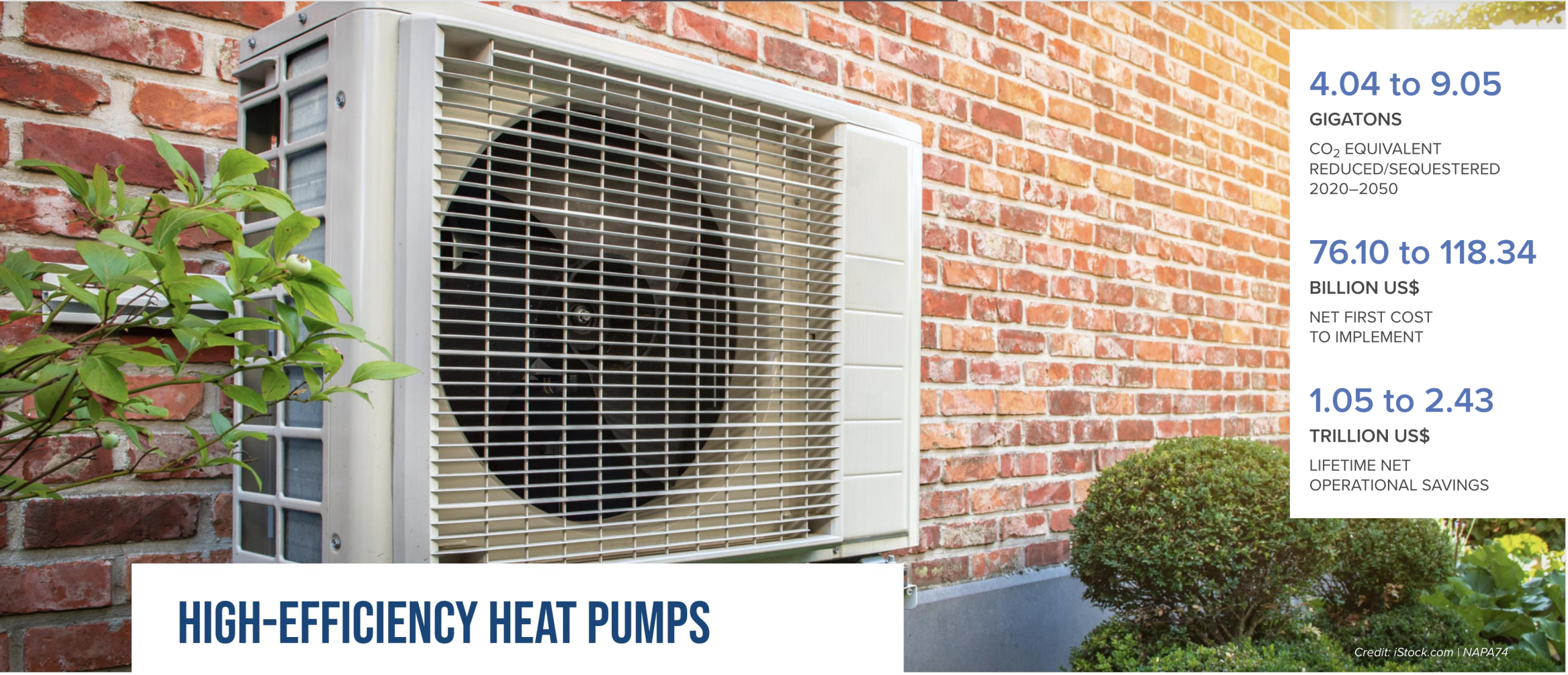
$CoO_2(s) + Li^+ + e^- \longleftrightarrow LiCoO_2$





How does distributed energy storage work?





4.04 to 9.05
GIGATONS
CO_2 EQUIVALENT
REDUCED/SEQUESTERED
2020–2050

76.10 to 118.34
BILLION US$
NET FIRST COST
TO IMPLEMENT

1.05 to 2.43
TRILLION US$
LIFETIME NET
OPERATIONAL SAVINGS

Credit: iStock.com | NAPA74

HIGH-EFFICIENCY HEAT PUMPS

Heat pumps extract heat from the air and transfer it—from indoors out for cooling, or from outdoors in for heating. With high-efficiency, they can dramatically lower building energy use.

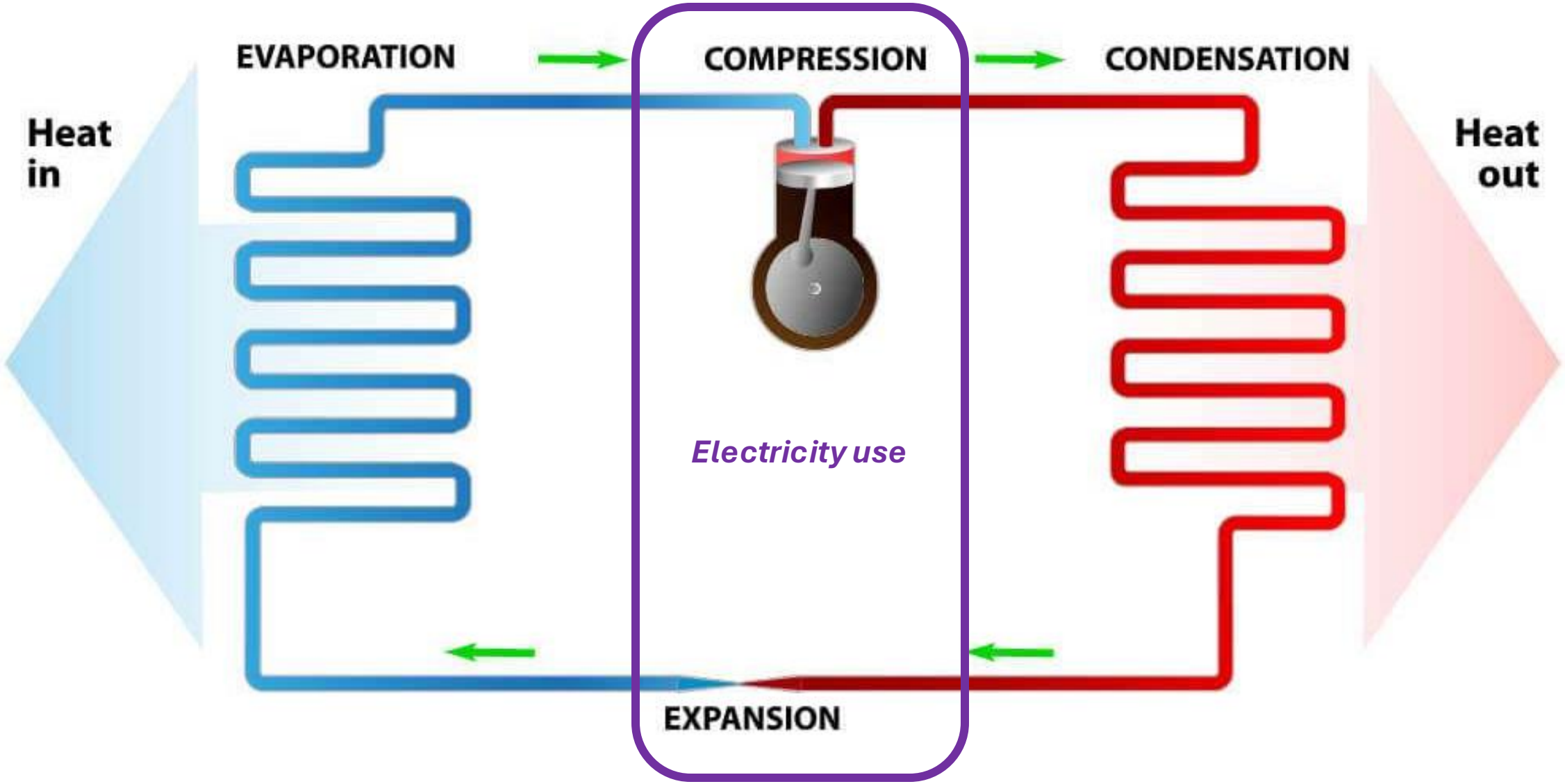
Drawdown solution

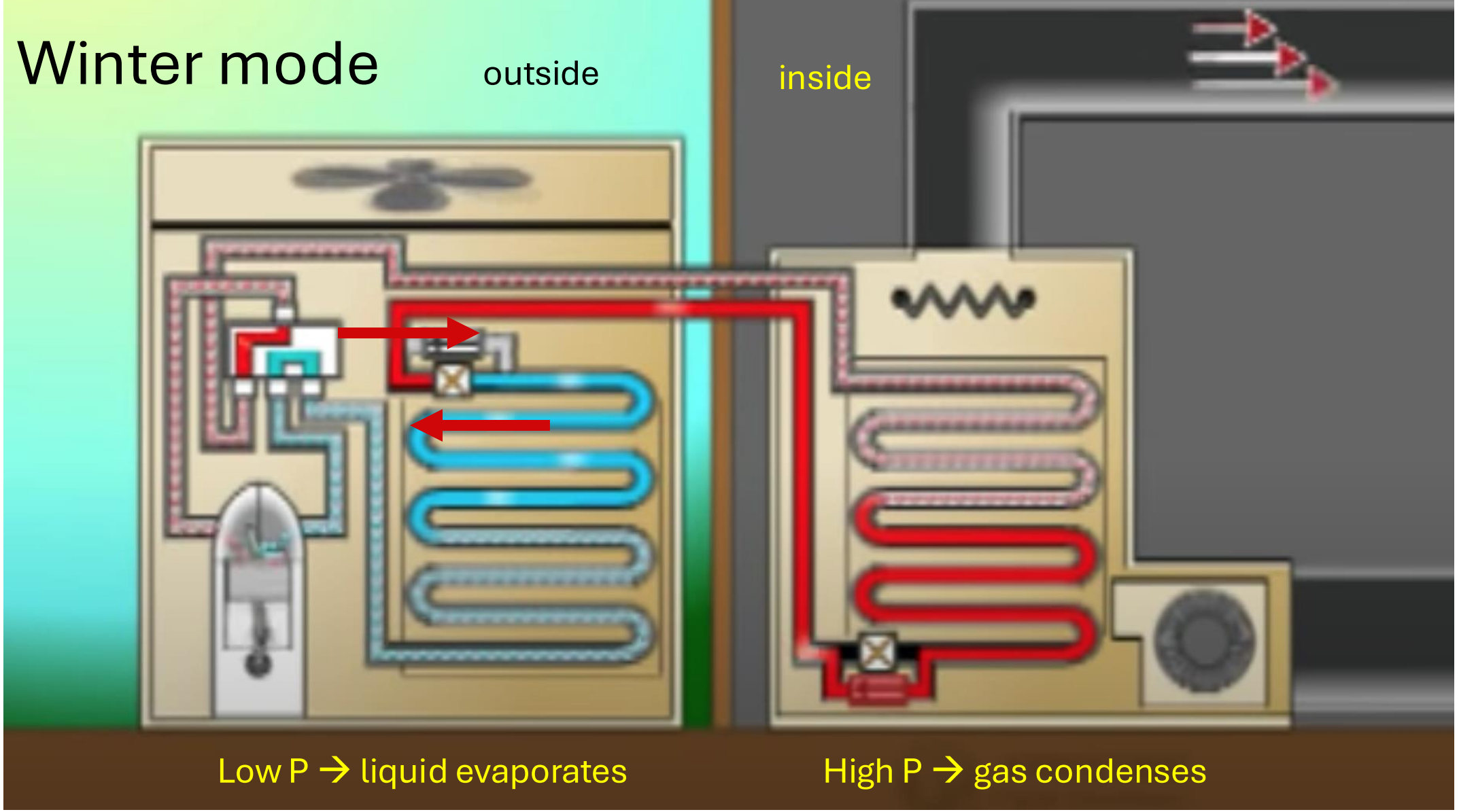
Heat pumps

- Worldwide, buildings use ~32% of all energy generated
  - >1/3 of that energy is for heating or cooling
- Increased efficiency in heating and cooling could cut this energy use by up to 30-40% and replace fossil fuel-powered heat and lower efficiency air conditioners

- **Heat pumps transfer heat between the inside and outside of a building (using a small amount of energy)**

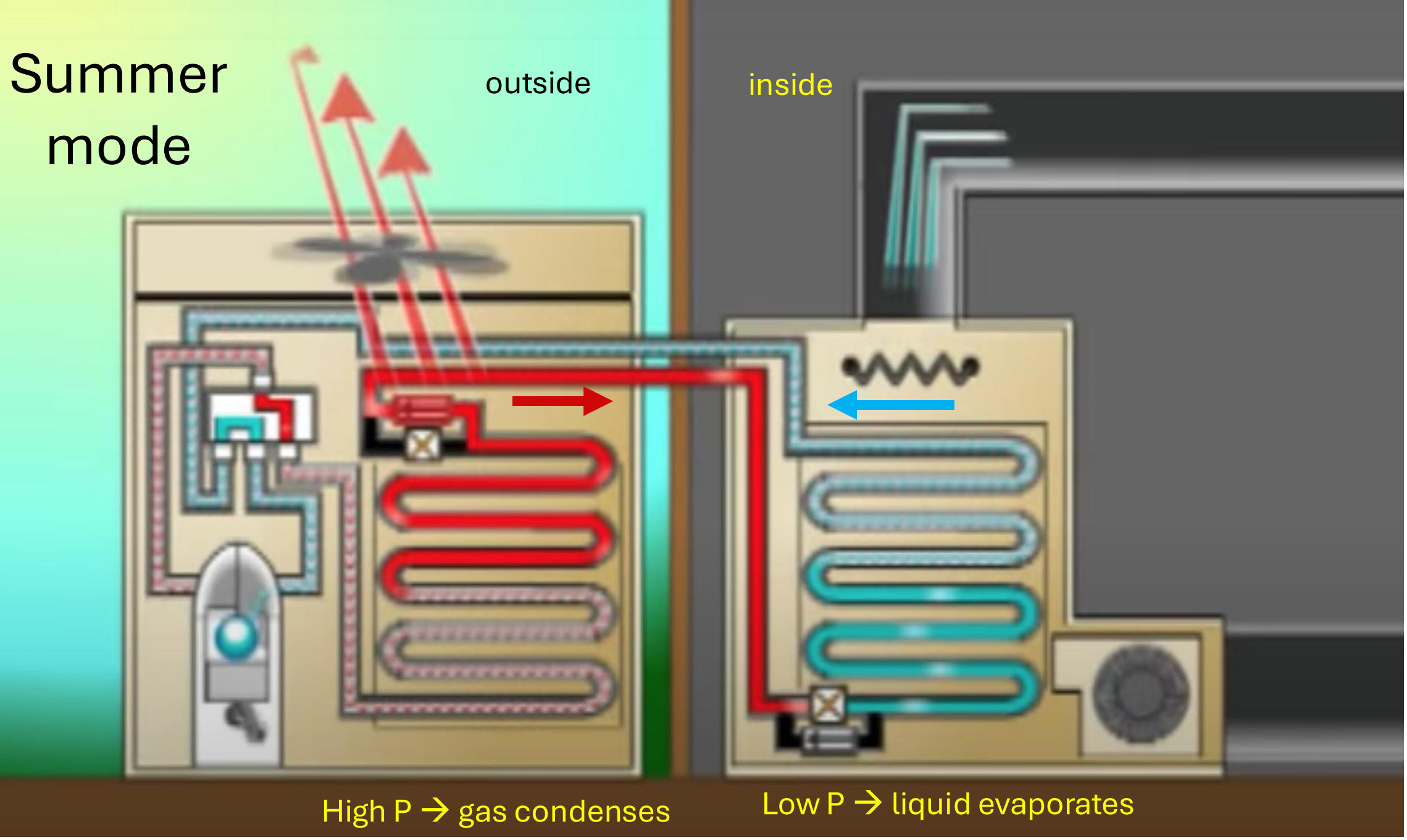
Schematic of a heat pump





Evaporation: $\Delta H > 0$ (accept heat from outside air),
$\Delta S > 0$
$\Delta G = \Delta H - T\,\Delta S$
ΔG gets more negative as T increases outside

Condensation: $\Delta H < 0$, (release heat to inside air),
$\Delta S < 0$
$\Delta G = \Delta H - T\,\Delta S$
ΔG gets less as T increases in the house



Exothermic, $\Delta H < 0$, release heat to outside air

Endothermic, $\Delta H > 0$, accept heat from inside air

1.33 to 2.48
GIGATONS
CO_2 EQUIVALENT
REDUCED/SEQUESTERED
2020–2050

82.70 to 97.76
BILLION US$
NET FIRST COST
TO IMPLEMENT

0.00
BILLION US$
LIFETIME NET
OPERATIONAL SAVINGS

Credit: Scott Bauer, U.S. Department of Agriculture (USDA)

BIOPLASTICS

Most plastics are made from fossil fuels, but bioplastics utilize plants as an alternative source of carbon. They often have lower emissions and sometimes biodegrade.

Drawdown solution

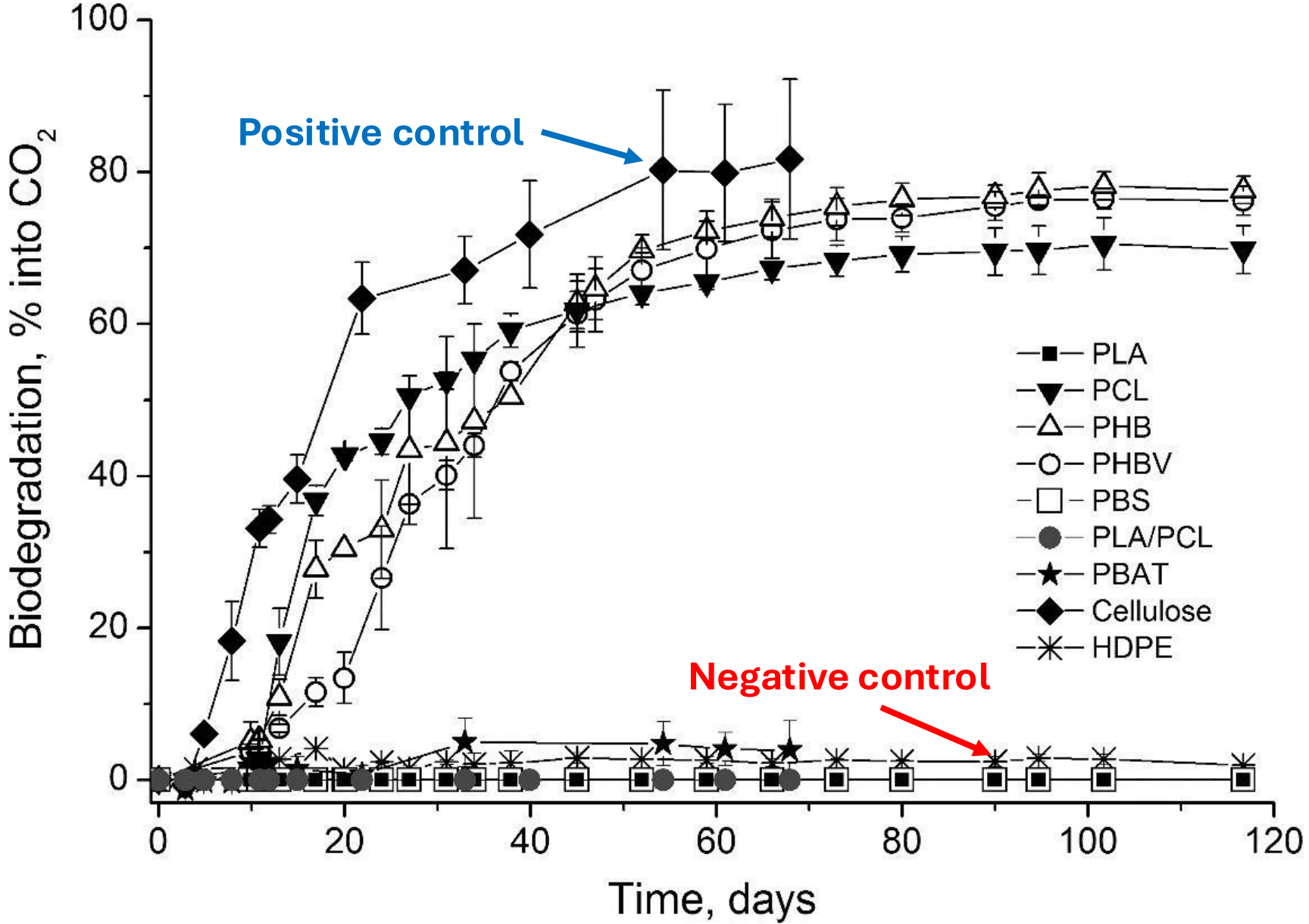
Bioplastics

- ~365 million metric tons of plastic are produced each year
  - Source: fossil fuels
  - 90% of current plastics could be sourced from plants instead
    - Manufacturing process produces less emissions
    - If/when they decompose, the CO_2 generated was "new" CO_2 rather than from a fossil source

BUT: most bioplastics only decompose under industrial conditions, and in landfills they often create methane (stronger greenhouse gas)

…so really we should greatly reduce our use of single-use plastics…then make sure bioplastics are properly sorted and sent to industrial composters.

Degradation of bioplastics



- 1st ~70 days: kinetic region for bioplastic degradation
- 70+ days: reaction is at equilibrium
- Bioplastic degradation rate decreases over time, reaches 0 at equilibrium
- HDPE negative control and other materials at the bottom of the graph: these reactions are **kinetically controlled**

Source: Garcia-Depraect et al., *Bioresource Technology*, 2022

1.13 to 1.40

GIGATONS

CO_2 EQUIVALENT
REDUCED/SEQUESTERED
2020–2050

-26.90 to -35.50

BILLION US$

NET FIRST COST
TO IMPLEMENT

-4.18 to -1.73

TRILLION US$

LIFETIME NET
OPERATIONAL SAVINGS

Credit: GardenPhotos.com/Alamy Stock Photo

COMPOSTING

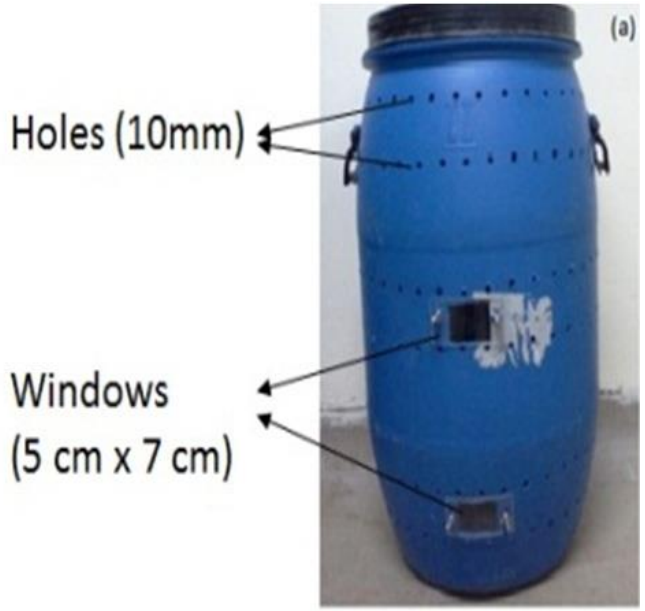
Composting can range from backyard bins to industrial-scale operations. Regardless, it converts organic waste into soil carbon, averting landfill methane emissions in the process.

Composting kinetics study

(a): unmodified drum (no air circulation)
(b): Air circulation holes but no turning
(c): air circulation holes + turning

k for (a) = -(-.2/30 days)
= 0.0067 day^{-1}

→ Reaction is **pseudo first-order** in organic material (but also dependent on O_2)



k for (c) = -(-.2/18 days)
= 0.0111 day^{-1}

Source: Manu, M.K. et al., *Procedia Environmental Sciences*, 2016