روش‌های ذخیره سازی انرژی

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About This Presentation

This slide show was first designed in July 2024 for presentation at a Talangor Group meeting. It was subsequently expanded and updated for a few other meetings.

My main message: Fossil fuels are cheaper than some sources of green energy, because we've been ignoring environmental and other mitigation costs. The "green premium" will vanish or even become negative when we do consider incidental costs.

Edition	Released	Revised	Revised	Revised
First	July 2024	Oct. 2024	Jan. 2025	

File: http://www.ece.ucsb.edu/~parhami/pres_folder/parh24-general-talk-green-energy-n-storage-250108.pdf

Why Energy Storage?

Energy production →  → Energy consumption

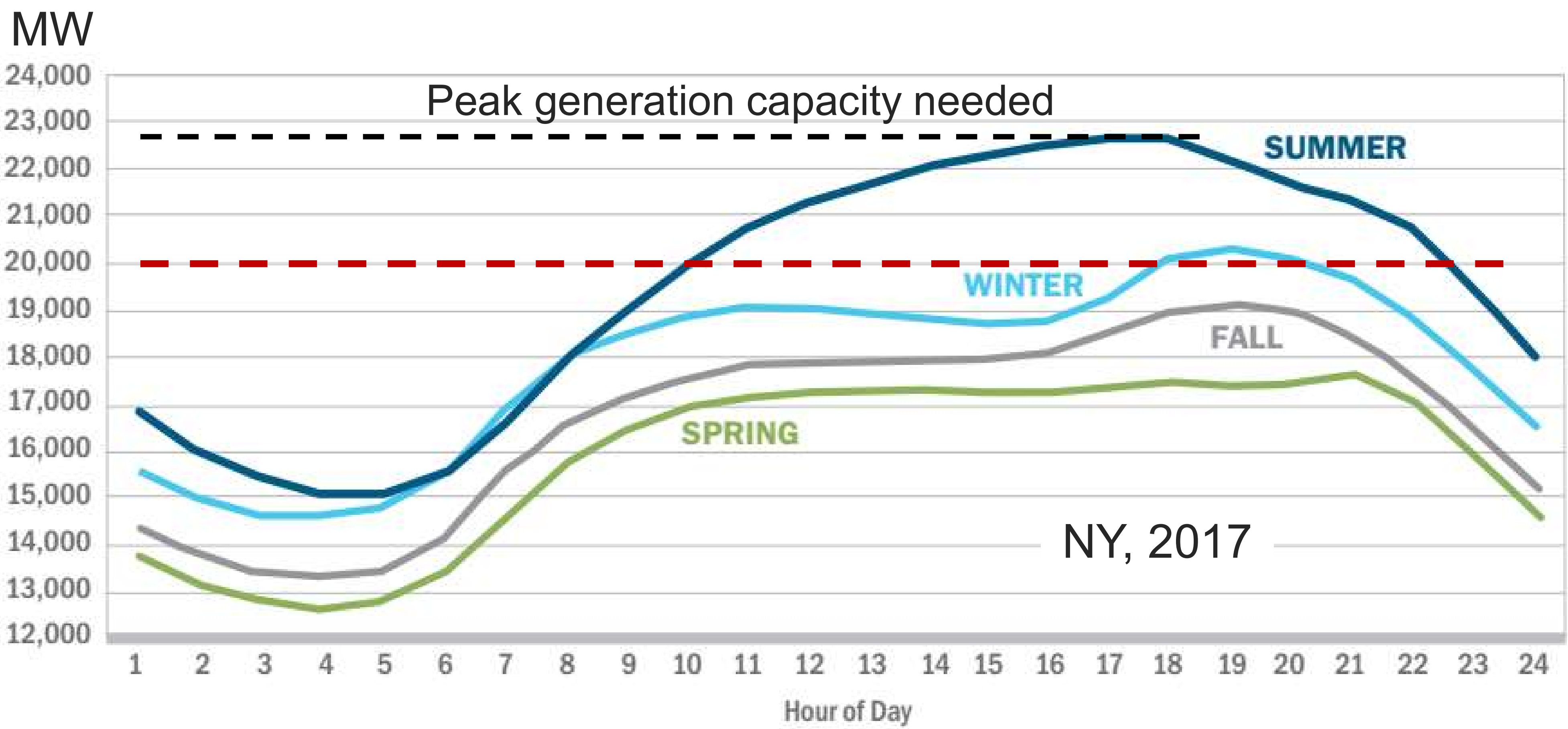
Data production →  → Data consumption

Crop production →  → Crop consumption

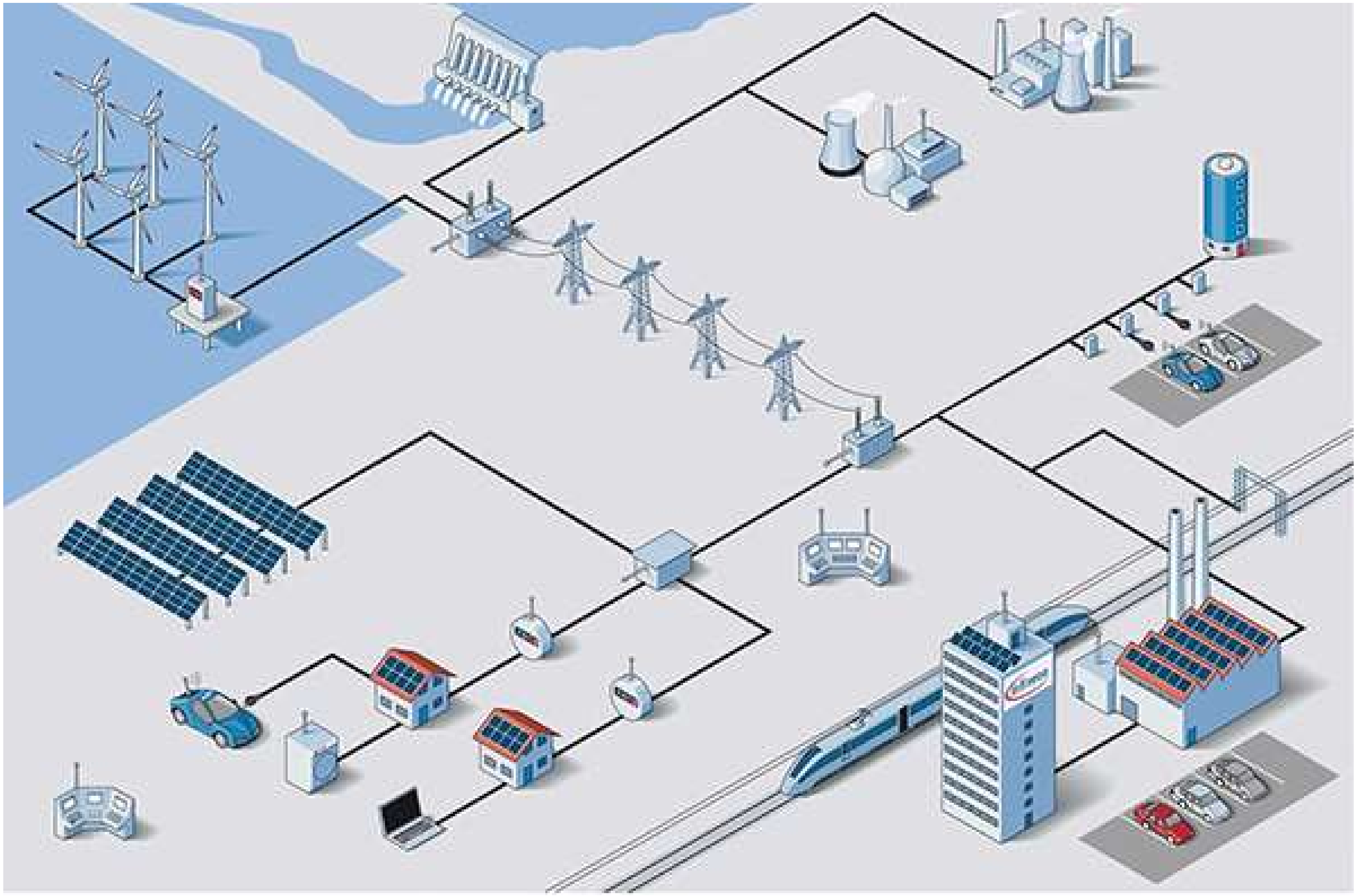
City Power Demand Variations

Demand has seasonal, daily, and hourly variations

Fluctuations a function of weather, weekday, business hours, etc.
Places with hot summers have higher peaks in summer due to A/C load



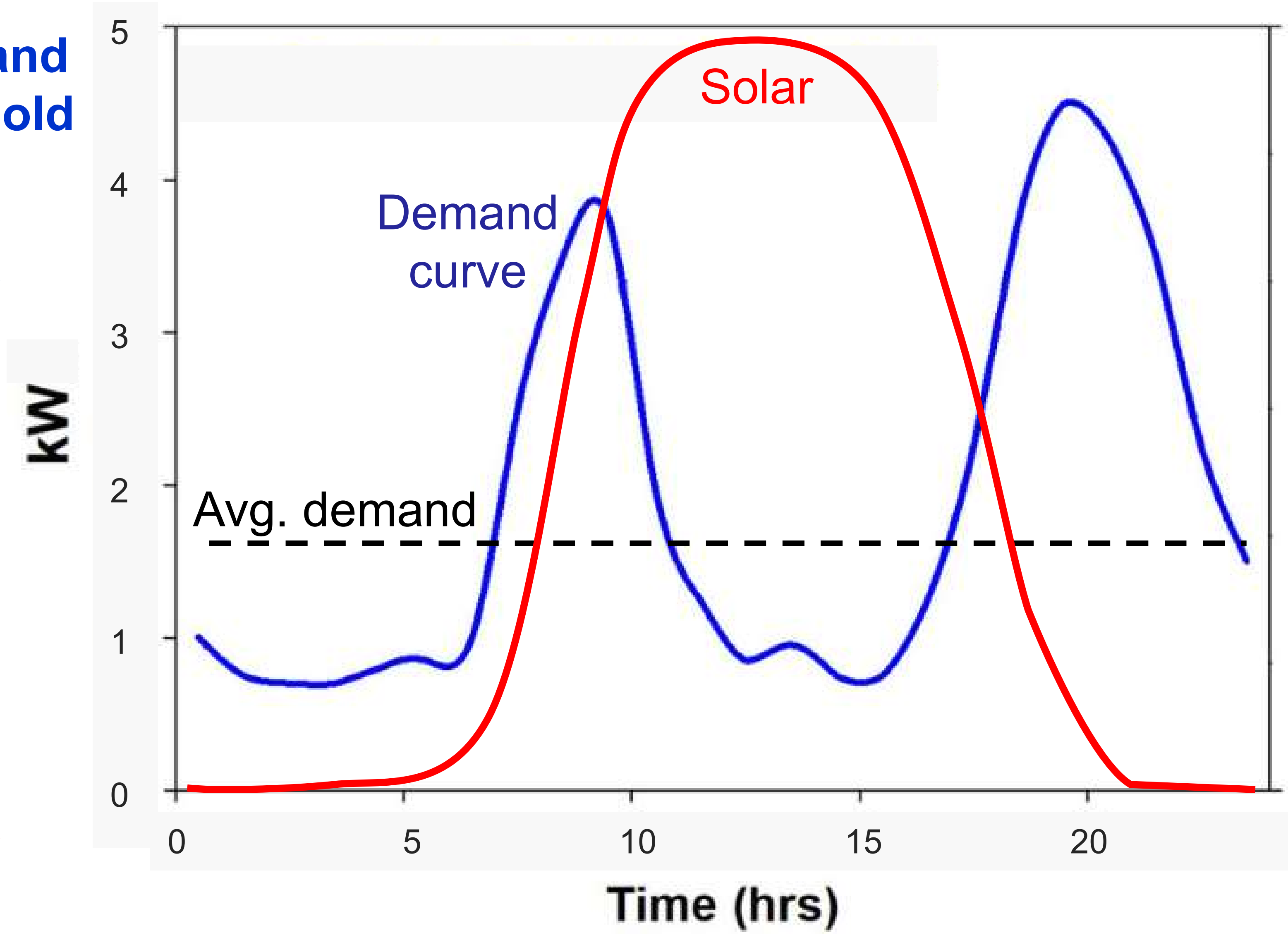
Grid Energy Generation and Storage



Base production, plus agile sources that can provide power on short notice

Household Power Demand Variation

Electricity demand avg. US household
~ 1.3 kW
~ 30 kWh / day
~ 11 MWh / year



Solar supply
~ 5.0 kW peak
~ 30 kWh / day
~ 11 MWh / year

The Third Industrial Revolution

Industrial Revolution (1760 CE)

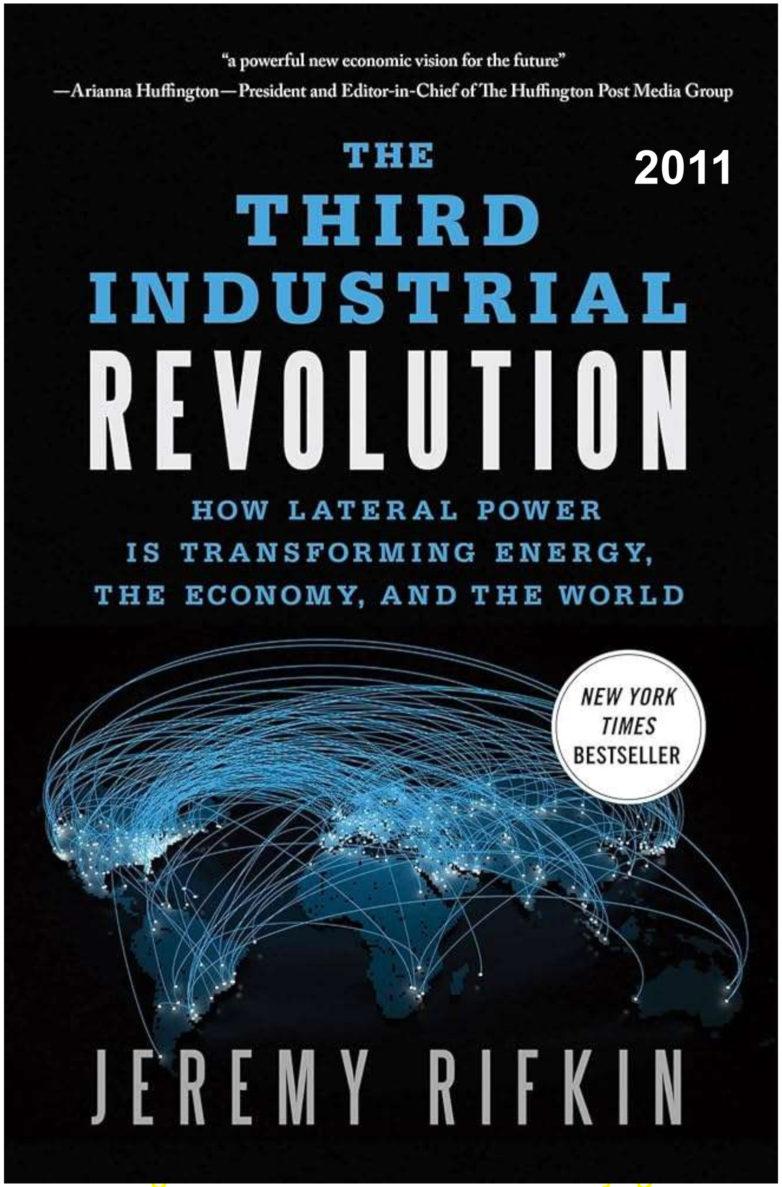
2nd Industrial Revolution (1900s)

Some count the Internet as the 3rd

Rifkin (economist / author) deems the Internet a part of the 2nd IR

Rifkin views distributed generation, storage, and sharing of electric energy as the 3rd IR (ongoing)

Visualized as an Internet of energy



Typical Nodes in a Worldwide Intergrid

World’s Largest Solar Farm

Bhadla Solar Park, India (14,000 acres) – 2.25 GW

Located in the village of Bhadla, Jodhpur District of Rajasthan

Only a tad larger than #2 Hainan Solar Park, China – 2.20 GW

Now 2.80 GW

Peak power (GW)	
CA	~ 78
Iran	~ 64
NY	~ 32
NYC	~ 12

https://www.ysgsolar.com/blog/15-largest-solar-farms-world-2021-ysg-solar

World’s Largest Wind Farm

Gansu Wind Farm, China (7000 units) – 10 GW (20 GW goal)
Largest in the US, Majave Wind Farm (600 units) – 1.5 GW
Largest off-shore wind farm, Hornsea 1, England – 1.2 GW

Peak power (GW)	
CA	~ 78
Iran	~ 64
NY	~ 32
NYC	~ 12

https://www.nw-rei.com/2021/08/20/worlds-largest-wind-farms/

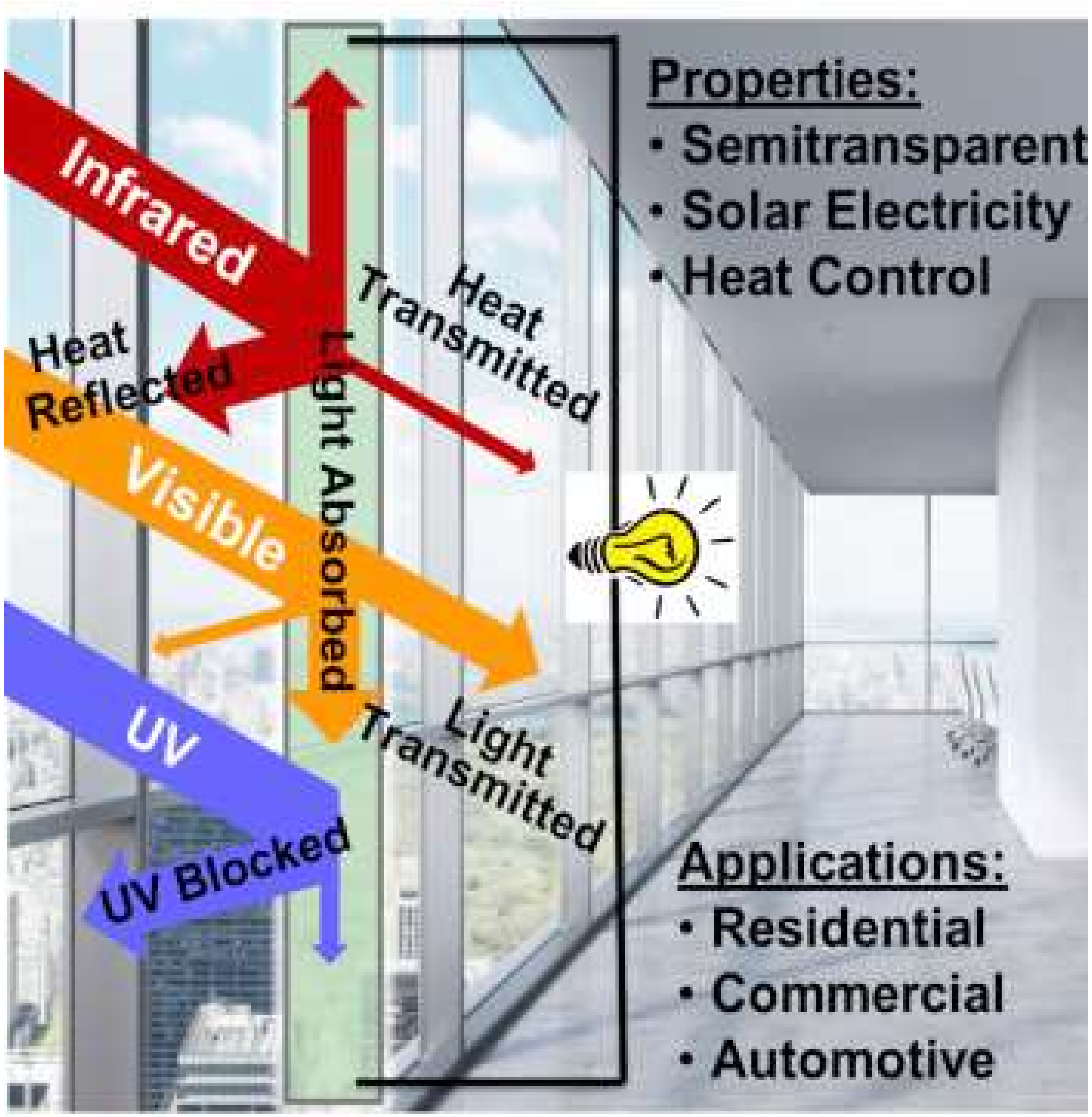
Bricks that Harness & Store Energy

Our buildings will soon feature bricks that produce and store electric energy

Several alternatives (biologically-based, solar-powered, concrete batteries, and super-capacitors) are being tried

https://eandt.theiet.org/content/articles/2022/01/not-just-another-brick-in-the-wall/

Transparent Solar Panels

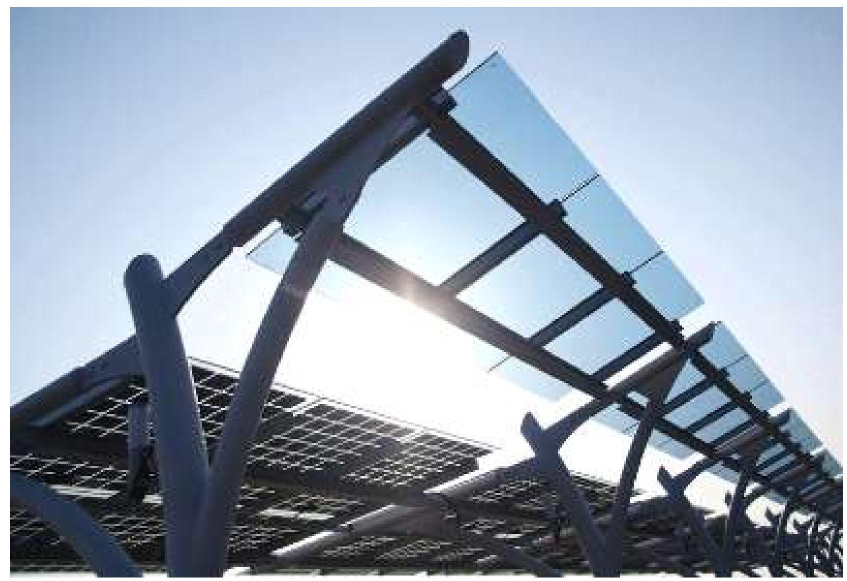


Office towers with glass surfaces can become electricity generators

Also offers shading & heat shield

Increasing the transparency reduces the conversion efficiency

UCLA installation of its own transparent solar cells offering up to 70% transparency



How to Talk About Reducing Emissions

Talking about so many millions or billions of tons of greenhouse-gas emission, or reduction thereof, is unhelpful
We need a reference point: 51 billion tons is the global total

Here is the share of emissions in each of 5 key categories:

1. Making things (plastic, steel, etc.)	31%
2. Plugging in (electricity)	27%
3. Growing things (food)	19%
4. Getting around (transportation)	16%
5. Keeping warm or cool (heating, A/C)	7%
	100%

Focusing only on the larger percentages won't cut it
Aiming for net-zero requires dealing with all of them

Gates, Bill, *How to Avoid a Climate Disaster* (2021)

Home Energy Usage and Storage

Average American home

- 11 MWh / year
- 30 kWh / day
- 1.3 kW power, average in 24 hours

Solar-cell energy output

- 5 kW when sunny (1 kW/m^2 x 5 m^2)
- 6 hours sunny on average ~ 30 kWh

Tesla Power Wall 3 (~$8500)

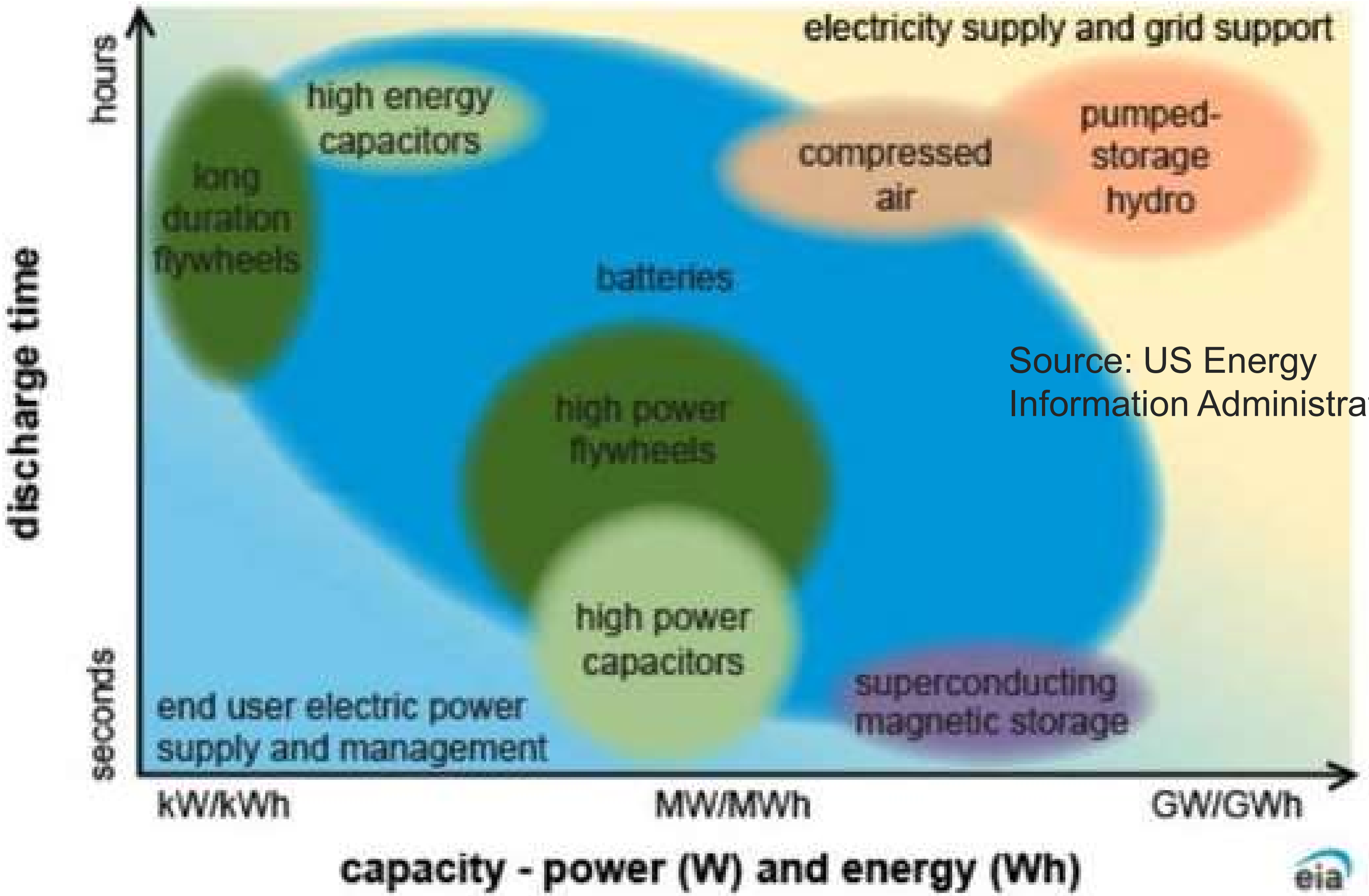
- Fridge size: 110 x 60 x 18 cm; 130 kg
- Li-ion, 14 kWh capacity
- Handles 12 kW of power continuously
- Loses 2.5% of capacity / year
- Lifespan ~ 10 years (warranty)

Power-Hungry Data Centers

Rapidly-expanding use of energy-intensive AI applications

Data-center operators are working on multiple fronts to reduce their energy requirements and to gain access to reliable energy supplies, up to and including building nuclear power plants nearby

Attributes of Energy Storage Methods



Source: US Energy Information Administration

Options for Storing Electrical Energy

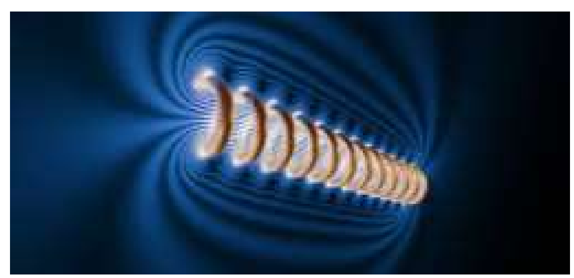
Mechanical
Flywheel; Pumped hydro; Gravity
Compressed air; Liquid piston

Chemical
Hydrogen; Biofuel; Biodiesel

Electrochemical
Supercapacitors; Batteries

Superconducting
Magnetic

Cryogenic
Liquid air



Flywheel Energy Storage

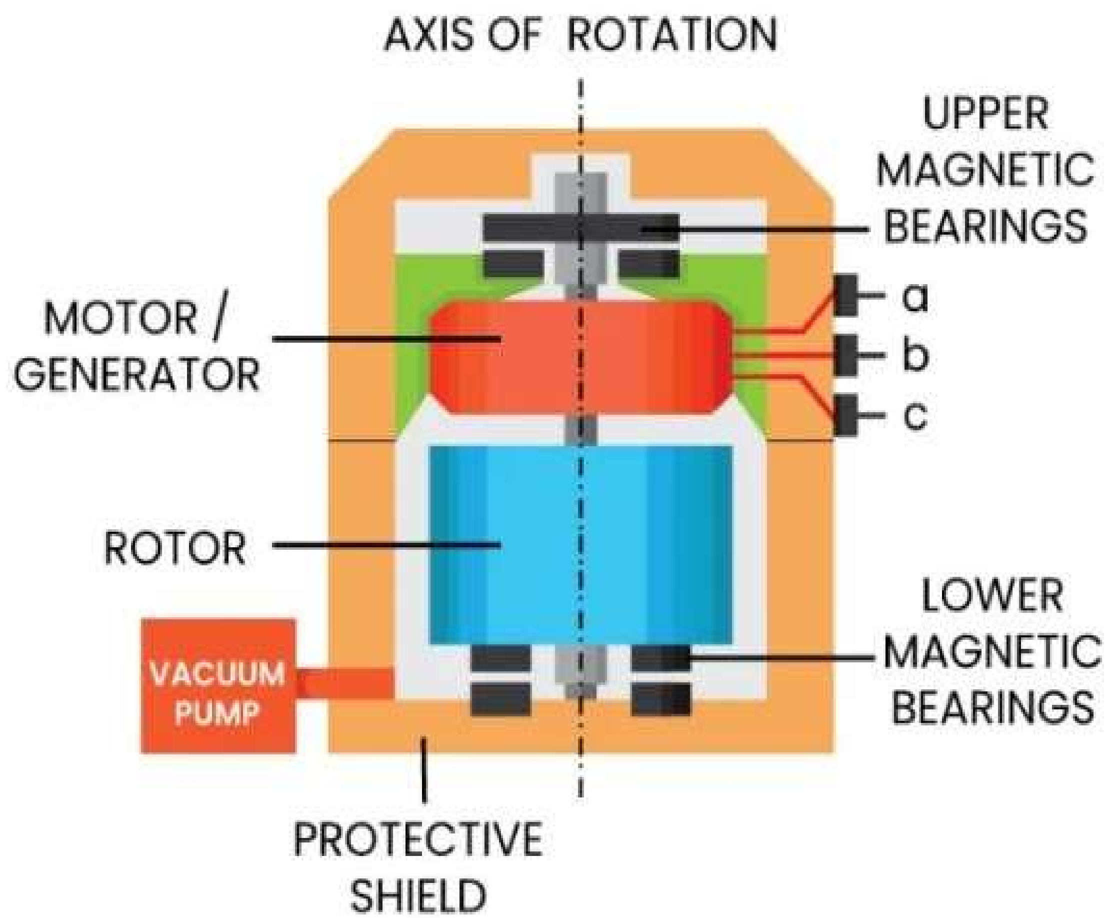
Older generation used a steel flywheel rotating on mechanical bearings

Newer devices use carbon-fiber rotors, which can store more energy for the same mass

Magnetic bearings and high vacuum, have led to ~85% round-trip efficiency

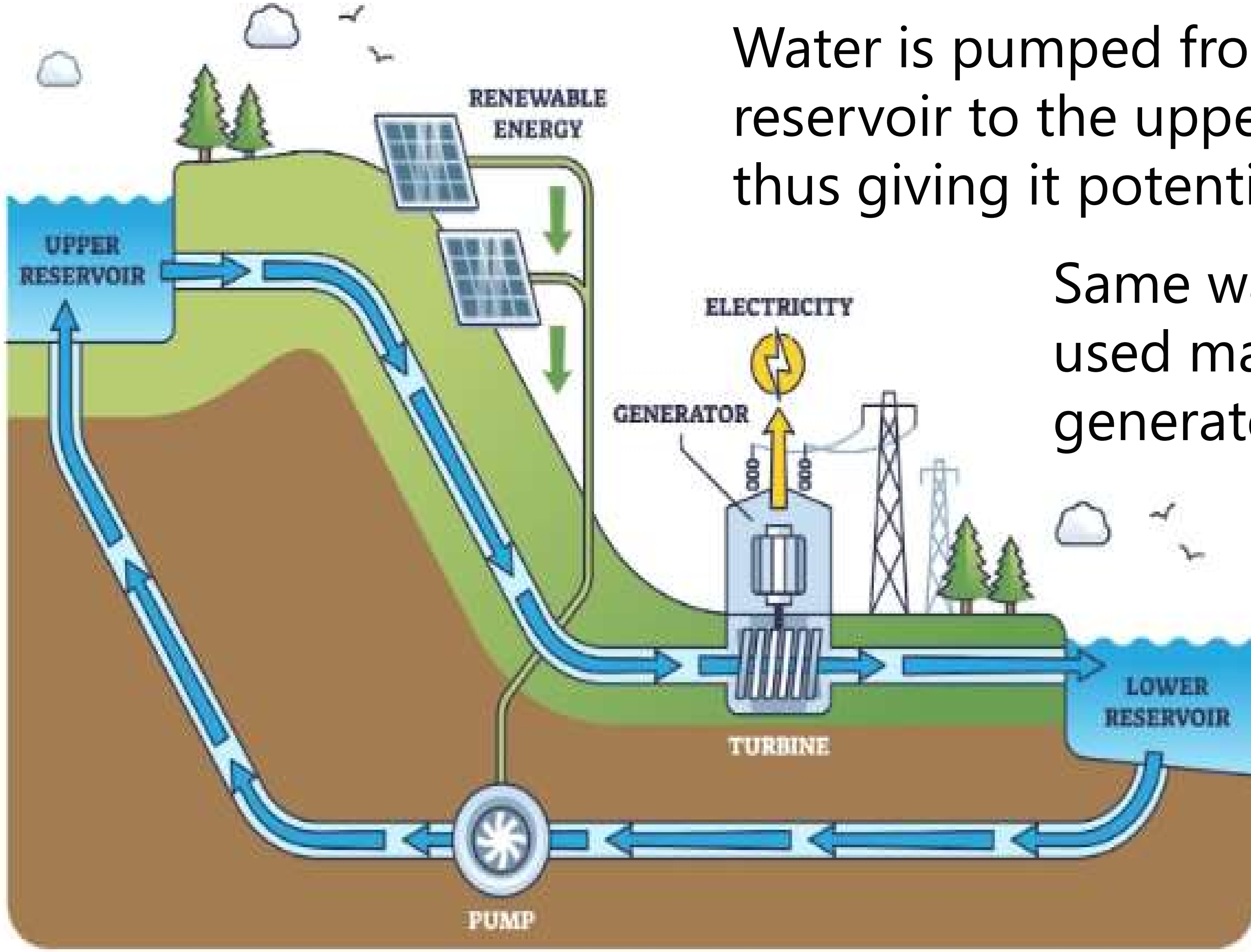
Capacities: 3-133 kWh

Charging: < 15 minutes



Flywheel: Old, Proven Technology

Gravity Energy Storage: Pumped Hydro



Water is pumped from the lower reservoir to the upper reservoir, thus giving it potential energy

Same water can be used many times to generate electricity

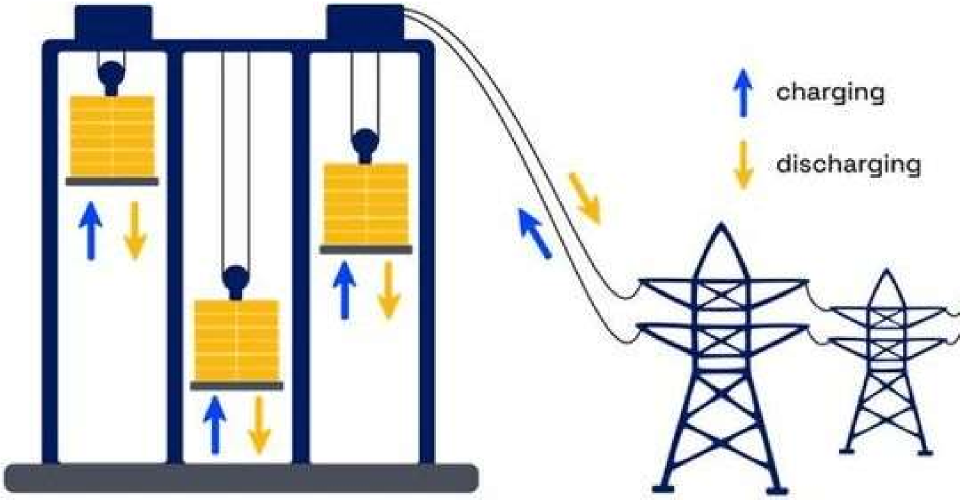
Gravity Energy Storage: Moving Weights

Excess energy is used to raise large concrete or steel blocks, giving them potential energy

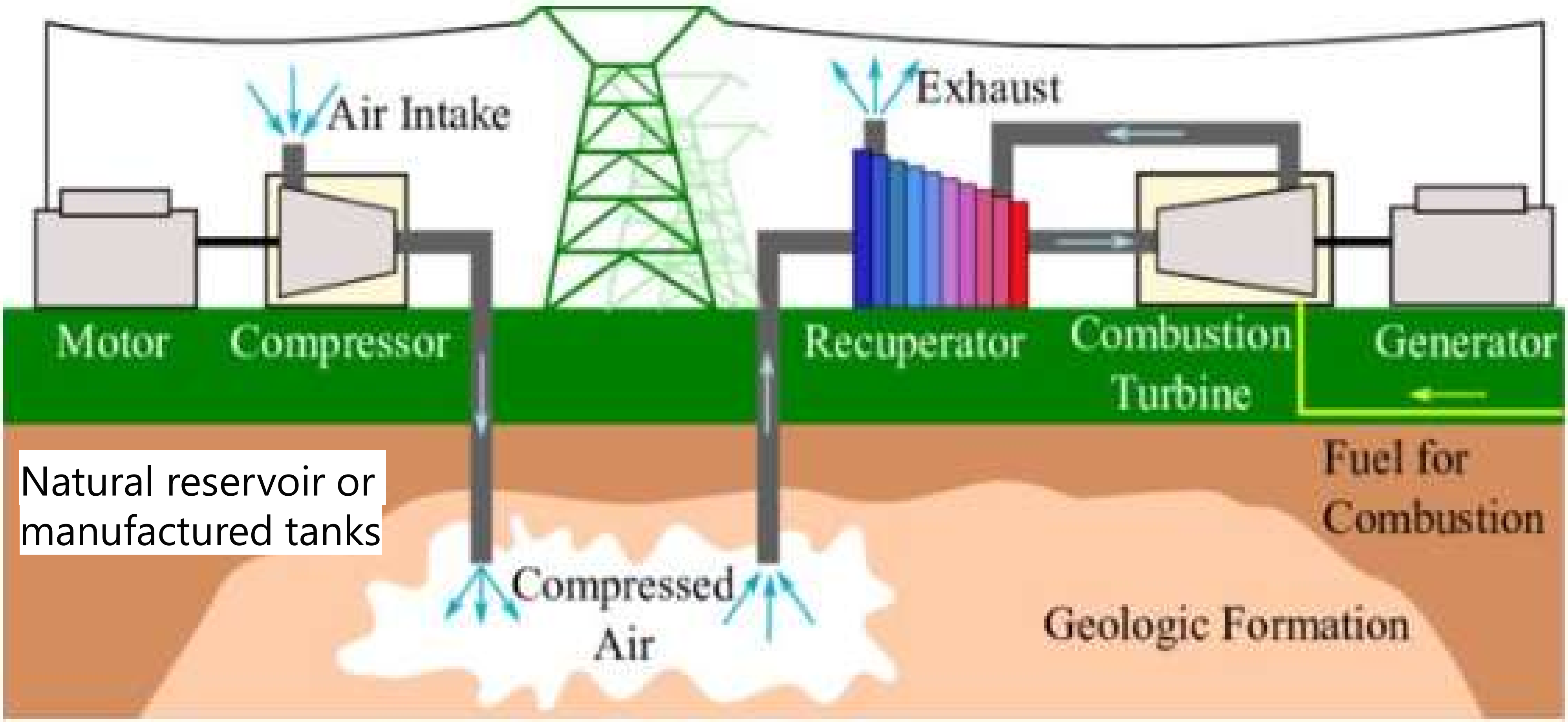
Then, lowering the blocks can generate electricity

Round-trip efficiency ~ 86%

https://www.youtube.com/watch?v=NhGECJTvDrc



Compressed-Air Energy Storage



Natural reservoir or manufactured tanks

Liquid piston storage is essentially the same, but with water, instead of air, compressed

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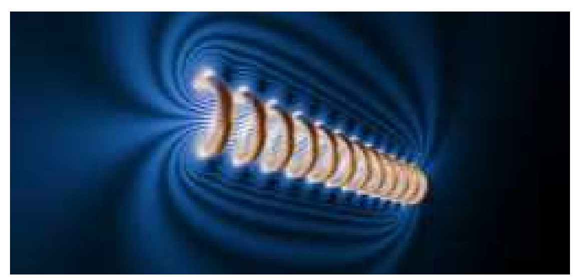
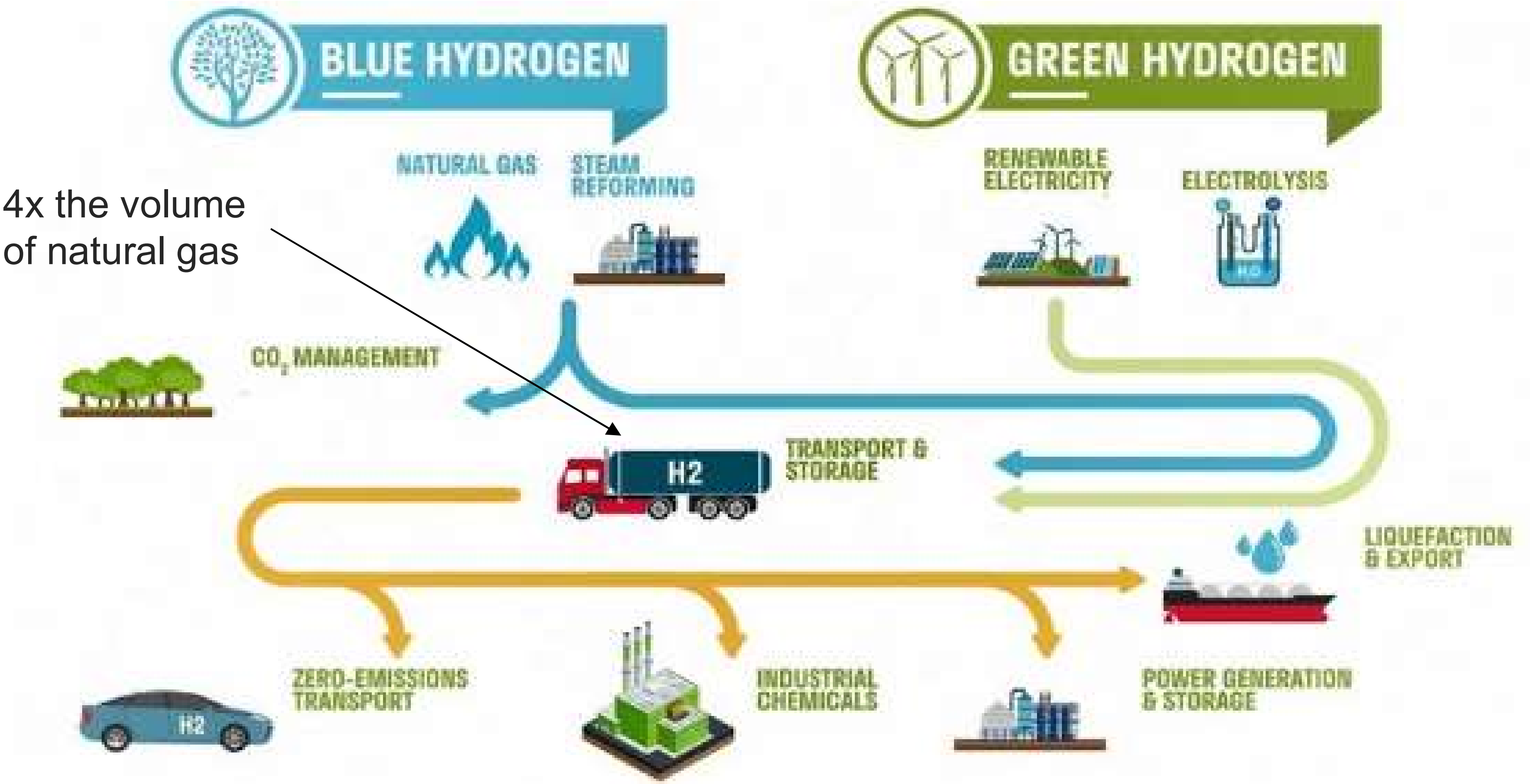


Green Hydrogen



4x the volume of natural gas

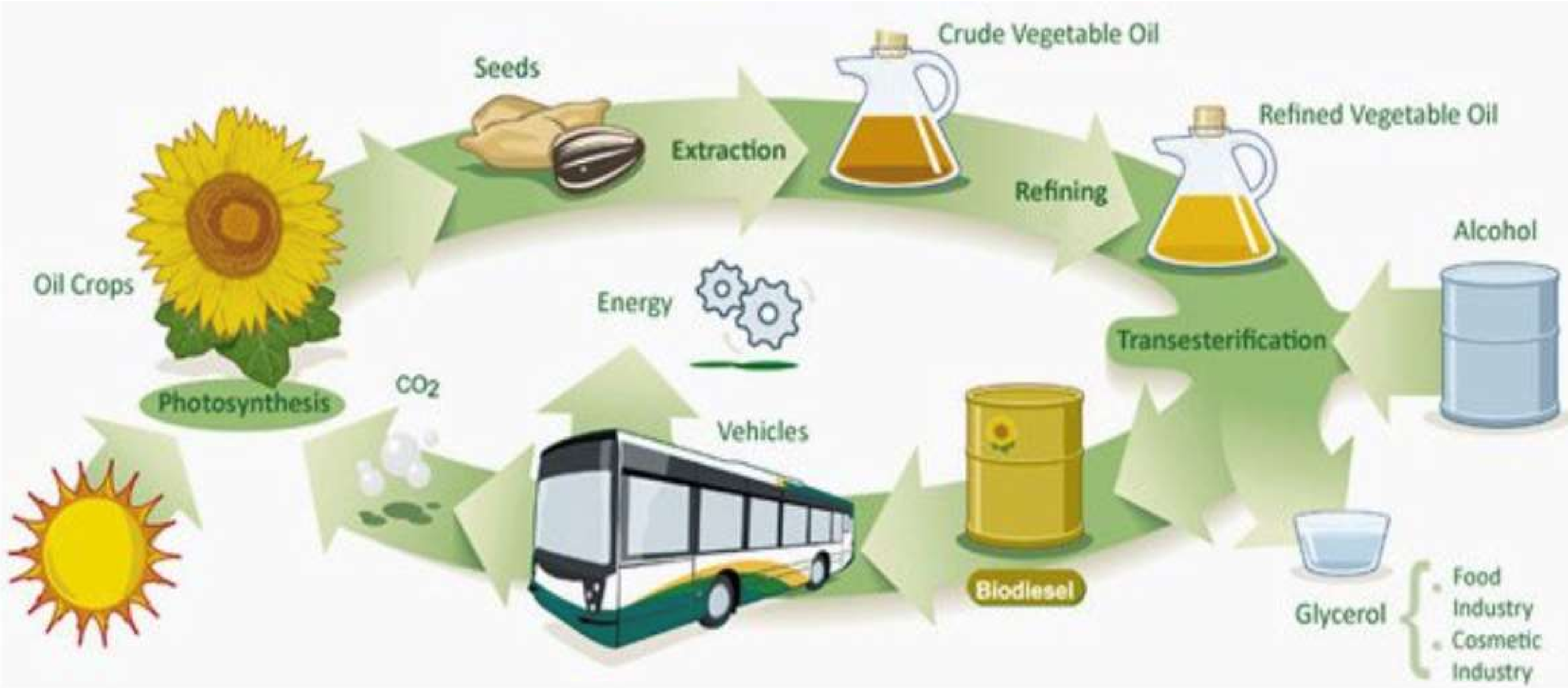
Store and transfer energy without emitting harmful pollutants
Clean, efficient power on demand through combustion engines or fuel cells

https://www.technologyreview.com/2024/06/18/1092956/scaling-green-hydrogen-technology-for-the-future/

Hydrogen-Electric Commuter Train

San Bernardino, California (*Guardian* story, September 3, 2024)
https://www.theguardian.com/environment/article/2024/sep/03/california-hydrogen-powered-train-air-quality-solution

The Biodiesel Fuel Cycle



Various parts of the cycle require expending energy
This is where the excess solar or wind energy comes in

What Is Biodiesel? https://greaterindiana.com/fuels/biodiesel/

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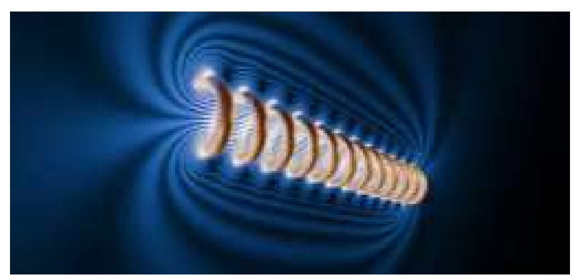
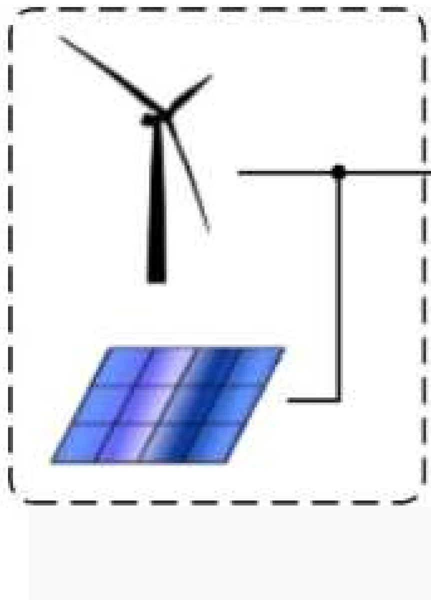
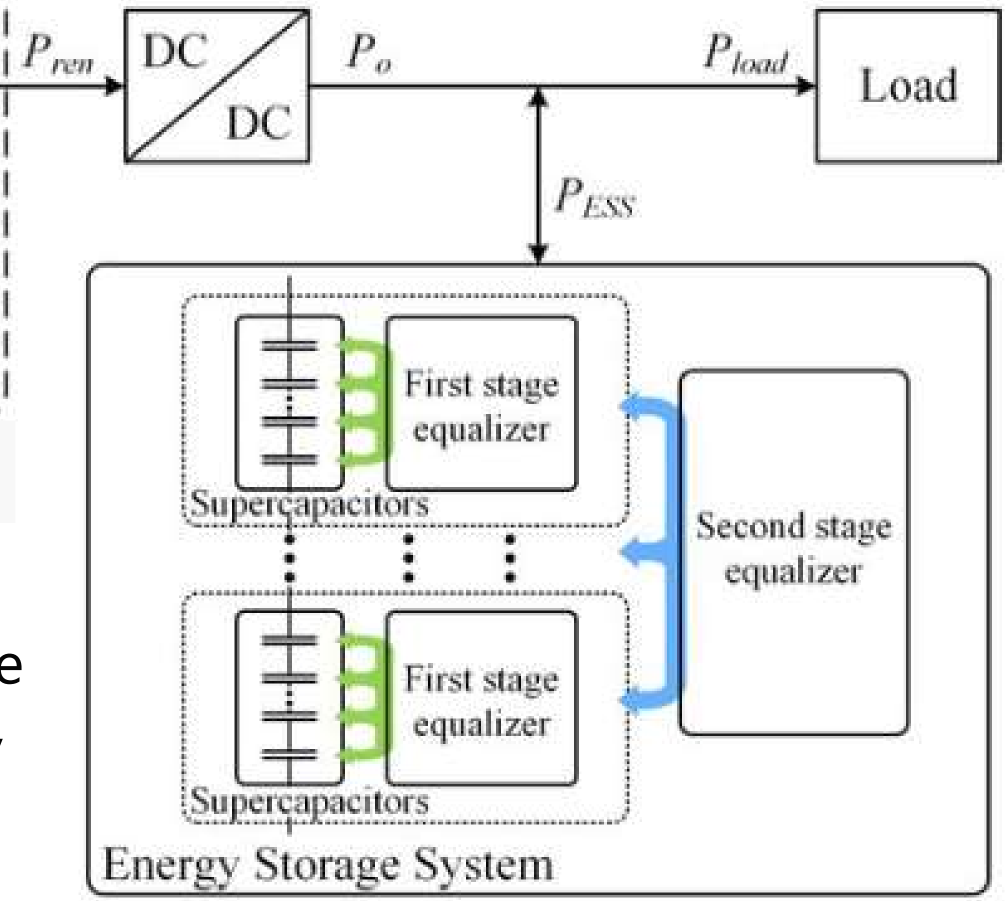


Supercapacitors for Energy Storage

Renewable
Power
Sources



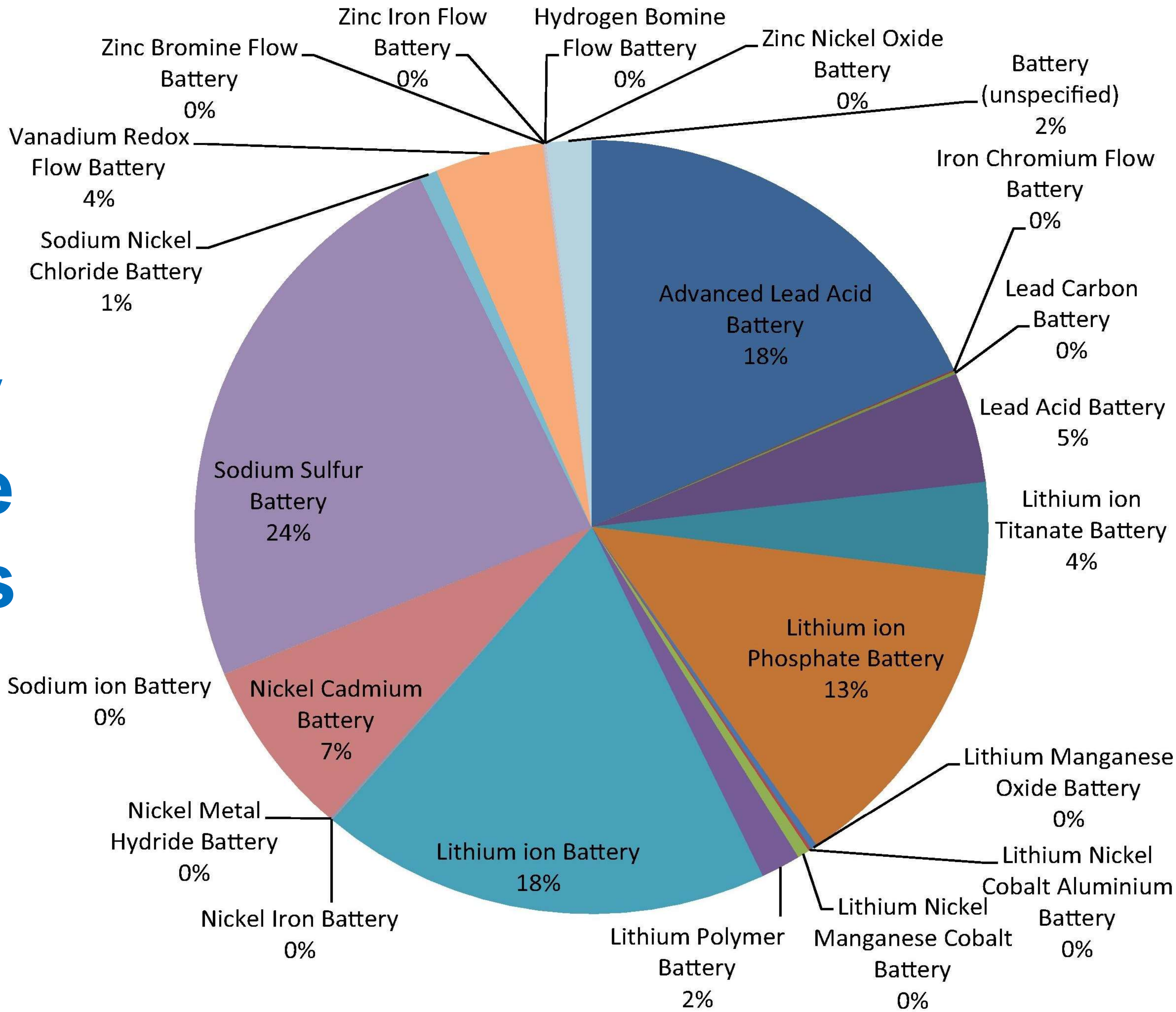


Capacitors: Higher power density, rapid charge/discharge

Batteries: Higher energy density per volume or weight

Source: A High-Efficiency Voltage Equalization Scheme for Supercapacitor Energy Storage System in Renewable Generation Applications

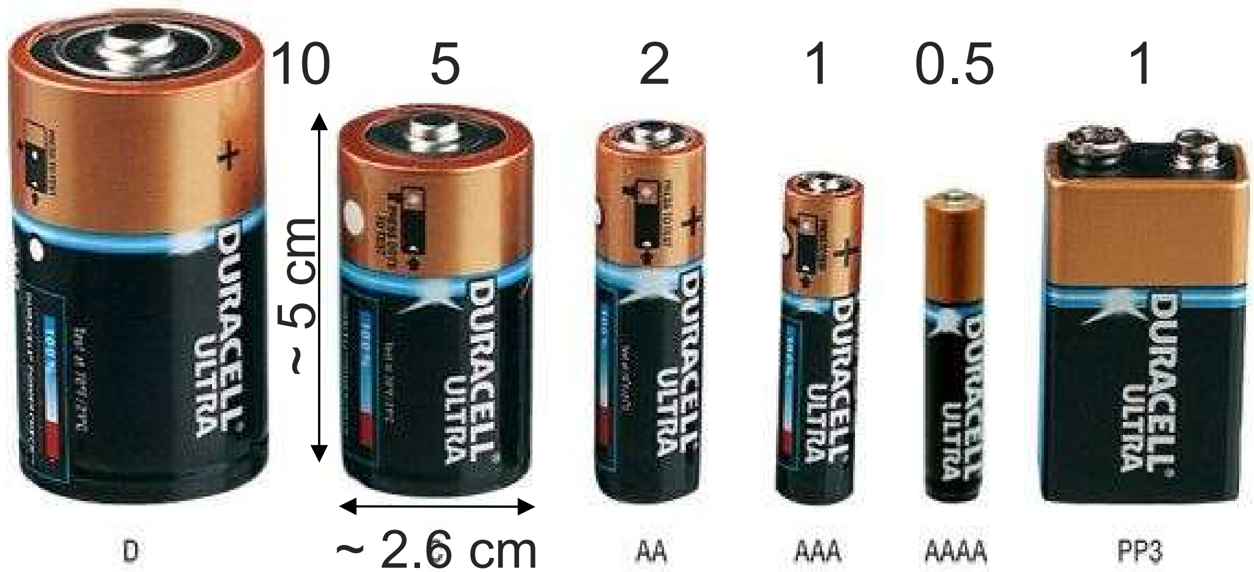
Battery Storage Options



Battery Voltage, Capacity, and Power

10 5 2 1 0.5 1 Ampere-hours

~ 5 cm



~ 2.6 cm

~ 2 cm

Tesla batteries on-line

~ 7 cm

~ 5K-10K cells

300-400 V AC motors

Tesla Power Wall: Another Look

Average American Home
- 11 MWh / year
- 30 kWh / day
- 1.3 kW power, average in 24 hours

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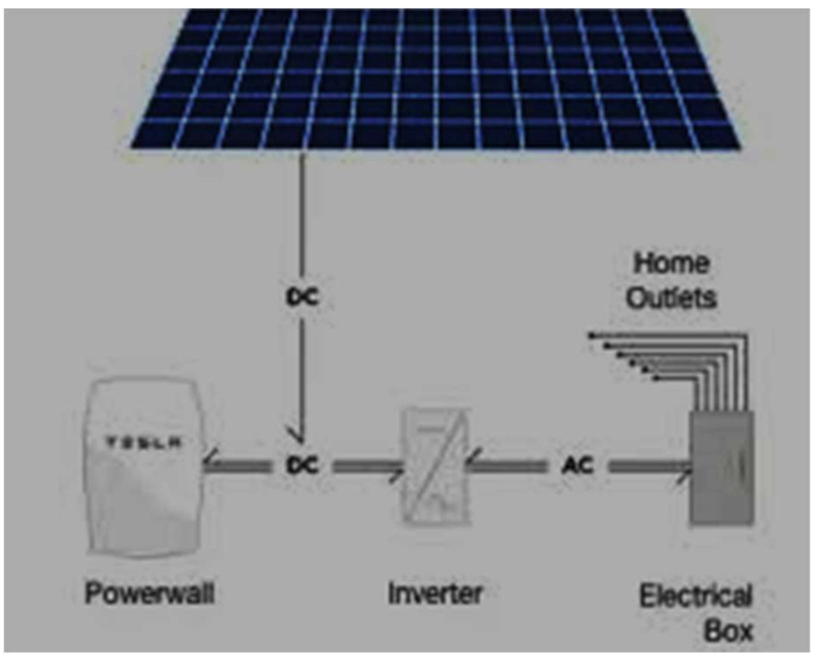

World's Largest Battery Installation

The Edwards & Sanborn solar-plus-storage project in Kern County, CA (4600 acres)

875 MW of solar power; 3287 MWh of BESS capacity (Capacity ~ 4 x Power)

1.9 million PV modules from First Solar and BESS units from LG Chem, Samsung, and BYD

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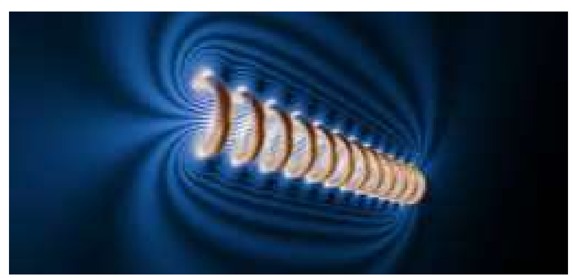
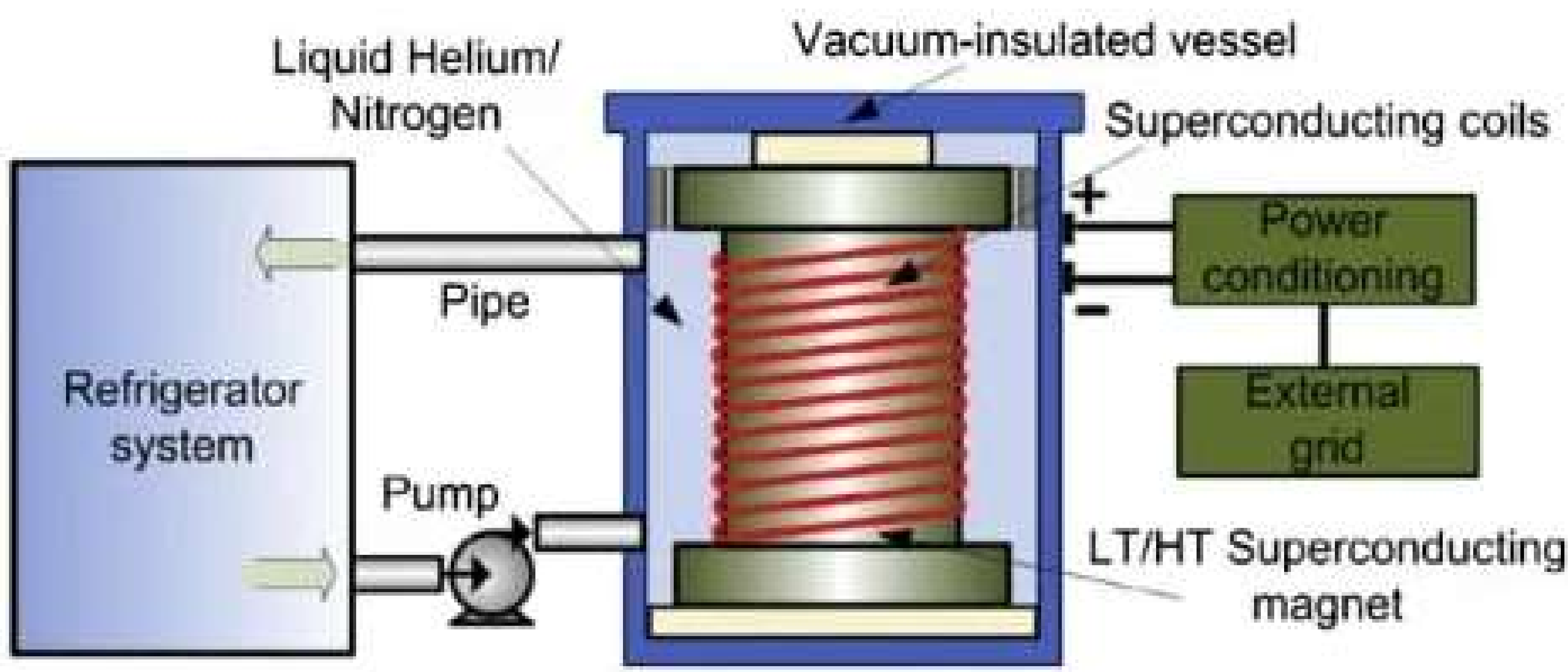


Superconducting Magnetic Storage

Energy stored as a magnetic field
Why superconducting?
Zero resistance means zero loss
End-to-end-efficiency > 90%
Capacity: 10 MW to 100 MW

Example superconducting material:
A niobium-titanium alloy
Critical temp 10 K (–263 C)
Advantages: Long life, fast start-up
Drawbacks: Need for refrigeration



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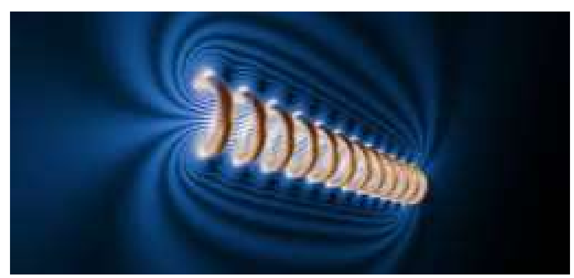


Cryogenic

Liquid air

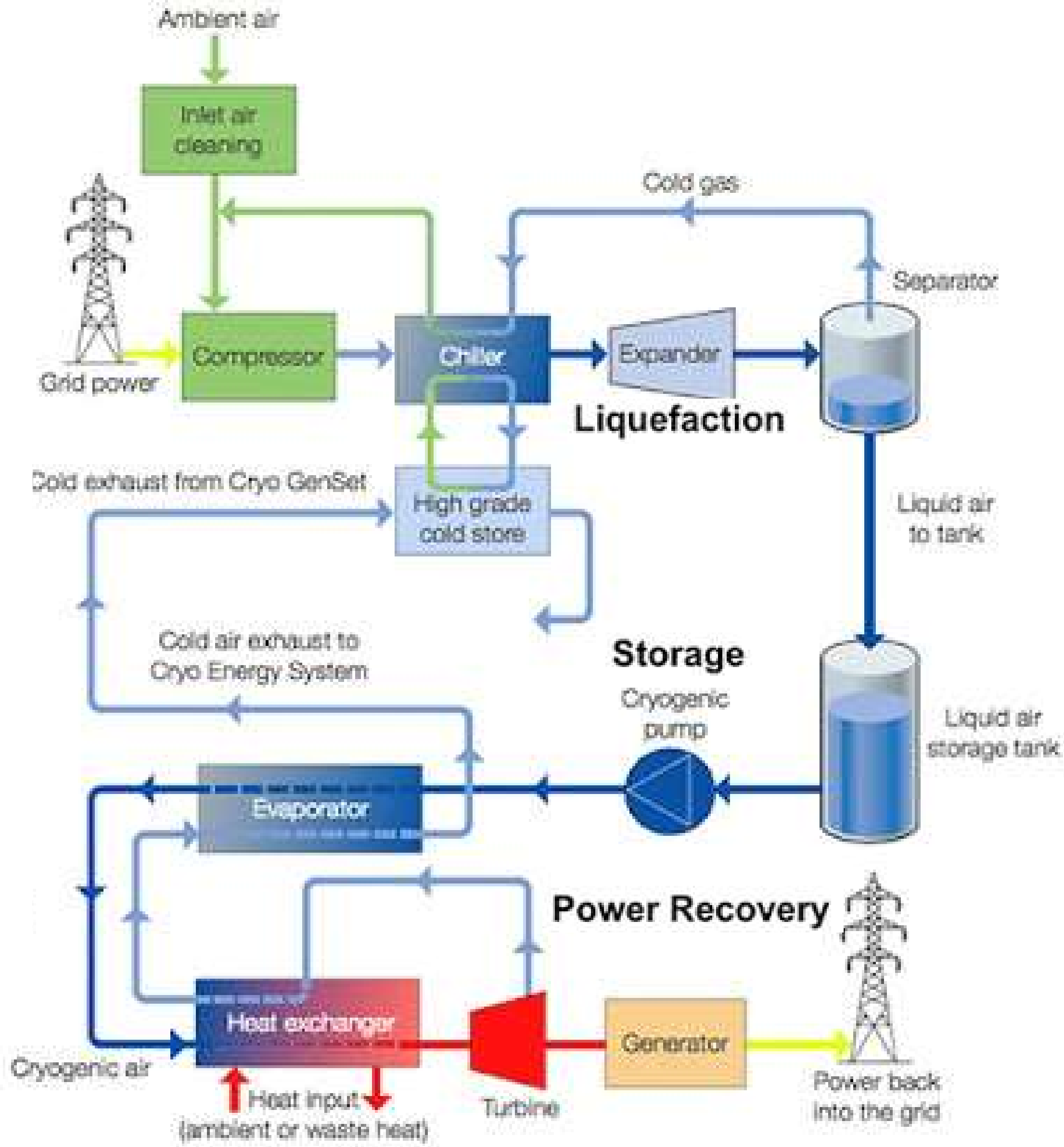
Cryogenic Liquid-Air Storage

Energy density, liquid air:
~100-200 Wh/kg

Cost: $200-500/kWh

Advantages:

Ability to use existing gas infrastructure
High cycling ability
No geographical constraints
Needs no exotic materials
Suitable for grid energy storage on a medium to large scale



Smart Electric Meters

	Penetration	Resolution of reading	Major smart meter manufacturer	Meter owner	Accessible to third parties
SWEDEN	100%	1 hour	Kamstrup	DSO	Accessible
ESTONIA	99%	1 hour	Landis+Gyr	DSO	Accessible
CANADA	82%	1 hour	Kamstrup	IESO, Utilities	On request
DENMARK	80%	1 hour	Kamstrup	DSO	On request
CHINA	80%	15 minutes	Sanxing Medical Electric	Energy providers	Not accessible
U.S.A	78%	15 minutes-1 hour	Duke Energy	Suppliers, Users	Based on utilities
JAPAN	64%	15-30 minutes	TEPCO	Suppliers, Users	Based on utilities
UK	52%	30 minutes	Sensus	Suppliers	On request
AUSTRALIA	24%	30 minutes	Intellihub	Suppliers	On request (charged)

A summary of the rollout of smart meters in selected countries. (Data for Australia and US from 2023, Canada, China, Japan and UK from 2022, and Sweden, Estonia and Denmark from 2020. DSO = distribution service operator, IESO = independent electricity system operator) Rui Yuan et al 2024,

Power delivered

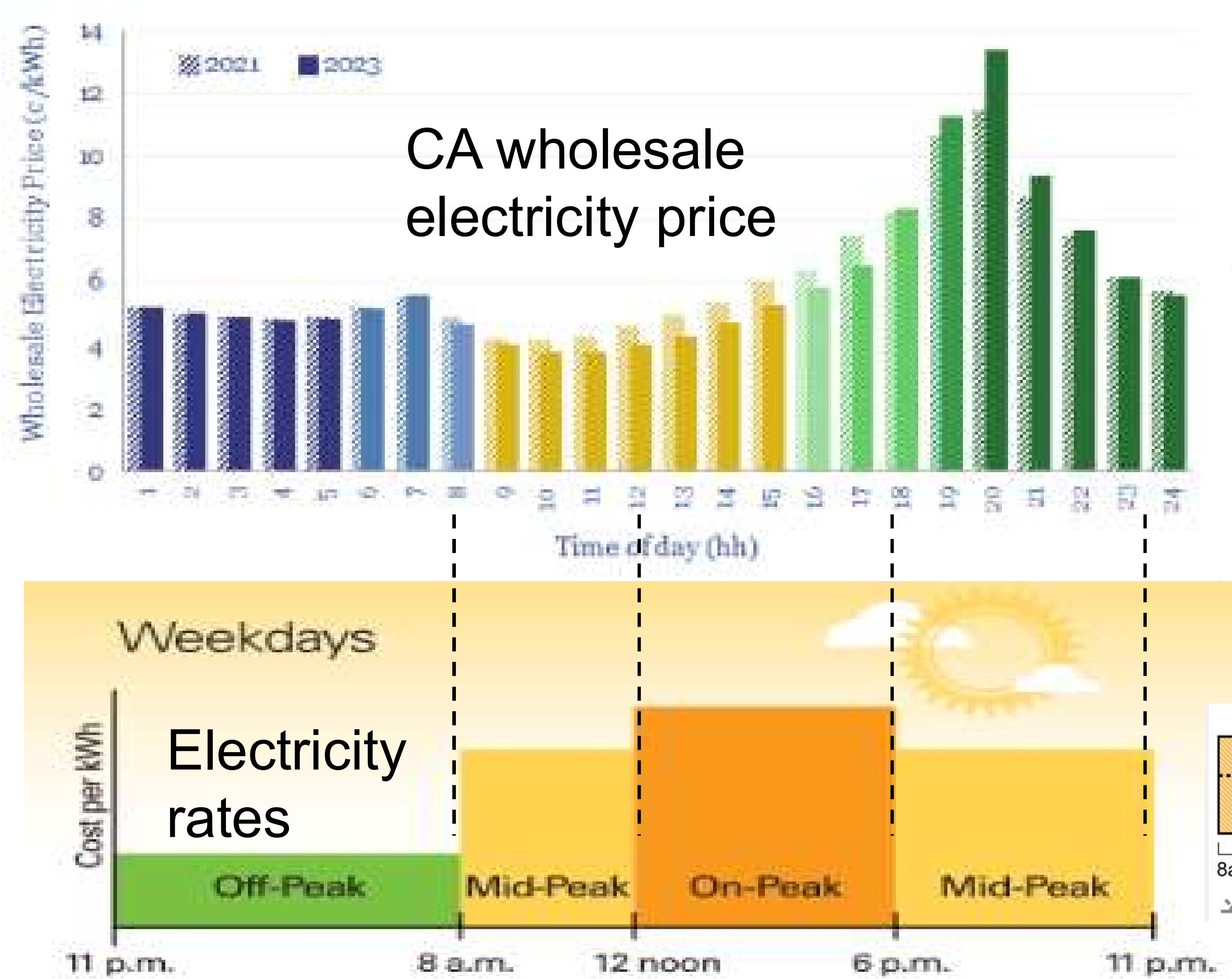
Power received

Net difference

Differential Pricing of Electric Power

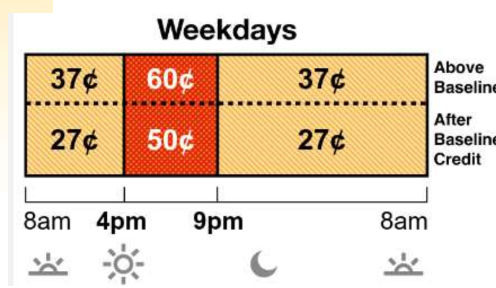
CA wholesale electricity price

Electricity rates

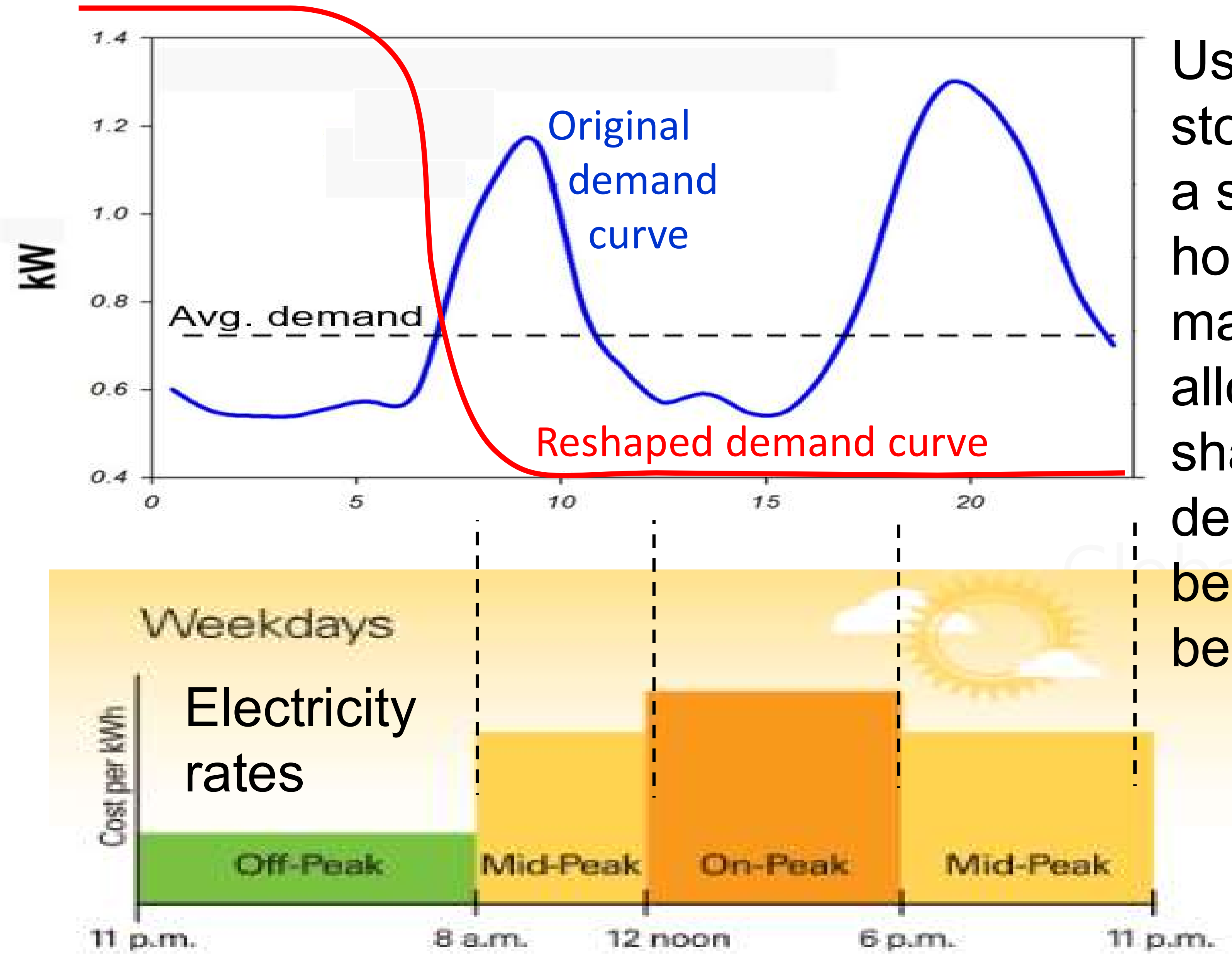


Managing energy use: Don’t operate washer, dryer, etc. in peak price hours

Sample Edison pricing



Shaping Your Demand Curve



Using energy storage with a smart home energy manager allows you to shape your demand to benefit from best prices

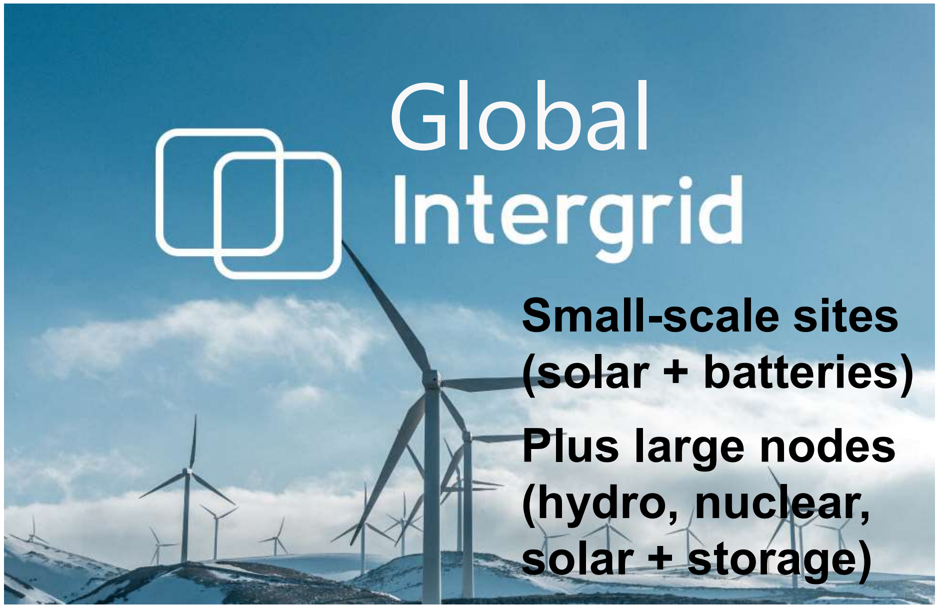
Conclusion

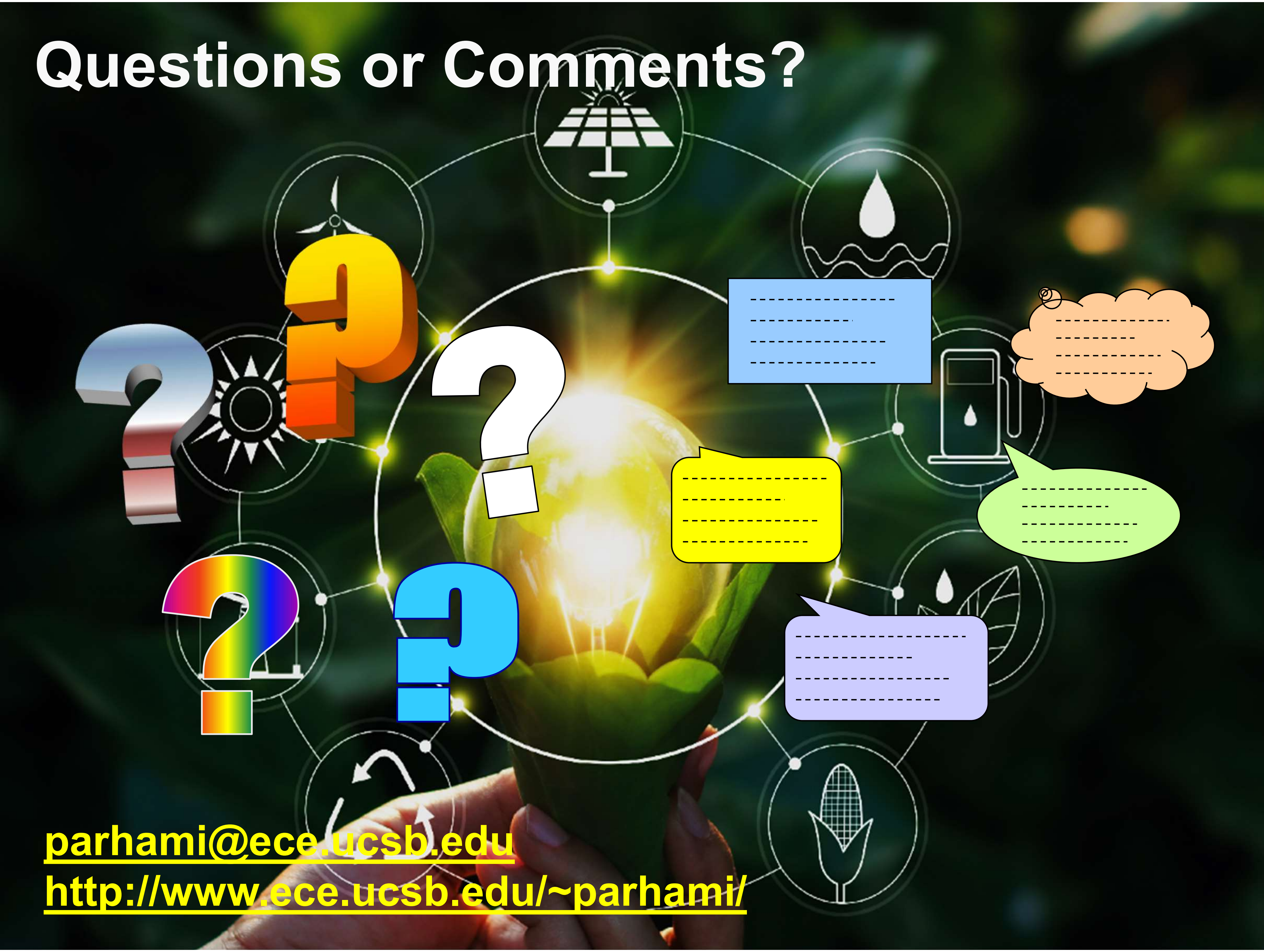
An Internet (Intergrid) of energy is quite practical

Grid energy prices going up and renewable energy becoming cheaper will lead to a crossover point (already reached?)

Smart meters and energy rate structure (buy, sell) need work

Complete electrification is the way to go: When energy suppliers use cleaner energy, all applications/users benefit

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http://www.ece.ucsb.edu/~parhami/