Energy Storage Technologies to Facilitate the Use of Renewable Energy

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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		

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

A Survey Paper and an Encyclopedia

Grid-Connected Energy Storage Systems: State-of-the-Art and Emerging Technologies

This article discusses pros and cons of available energy storage, describes applications where energy storage systems are needed and the grid services they can provide, and demonstrates different power electronic solutions.

By Glen G. Farivar, *Senior Member IEEE*, William Manalastas, Jr., Hossein Dehghani Tafti, *Senior Member IEEE*, Salvador Ceballos, Alain Sanchez-Ruiz, *Senior Member IEEE*, Emma C. Lovell, Georgios Konstantinou, *Senior Member IEEE*, Christopher D. Townsend, *Member IEEE*, Madhavi Srinivasan, and Josep Pou, *Fellow IEEE*

ABSTRACT | High penetration of renewable energy resources in the power system results in various new challenges for power system operators. One of the promising solutions to sustain the quality and reliability of the power system is the integration of energy storage systems (ESSs). This article investigates the current and emerging trends and technologies for grid-connected ESSs. Different technologies of ESSs categorized as mechanical, electrical, electrochemical, chemical, and thermal are briefly explained. Especially, a detailed review of battery ESSs (BESSs) is provided as they are attracting much attention owing, in part, to the ongoing electrification of transportation. Then, the services that grid-connected ESSs provide to the grid are discussed. Grid connection of the BESSs requires power electronic converters. Therefore, a survey of popular power converter topologies, including transformer-based, transformerless with distributed or common dc-link, and hybrid systems, along with some discussions for implementing advanced grid support functionalities in the BESS control, is presented. Furthermore, the requirements of new standards and grid codes for grid-connected BESSs are reviewed for several countries around the globe. Finally, emerging technologies, including flexible power control of photovoltaic systems, hydrogen, and second-life batteries from electric vehicles, are discussed in this article.

KEYWORDS | Battery energy storage system (BESS); energy storage system (ESS); grid codes; hydrogen; power electronic converter; renewable energy.

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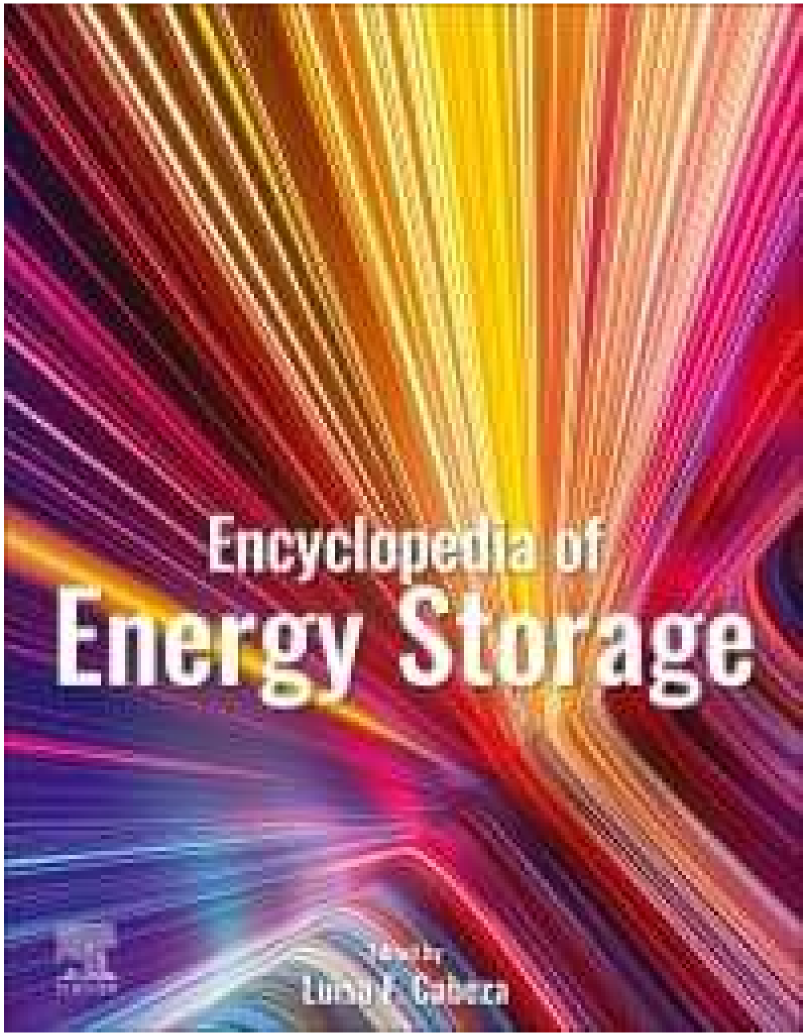


The Third Industrial Revolution

Industrial Revolution (1760 CE)

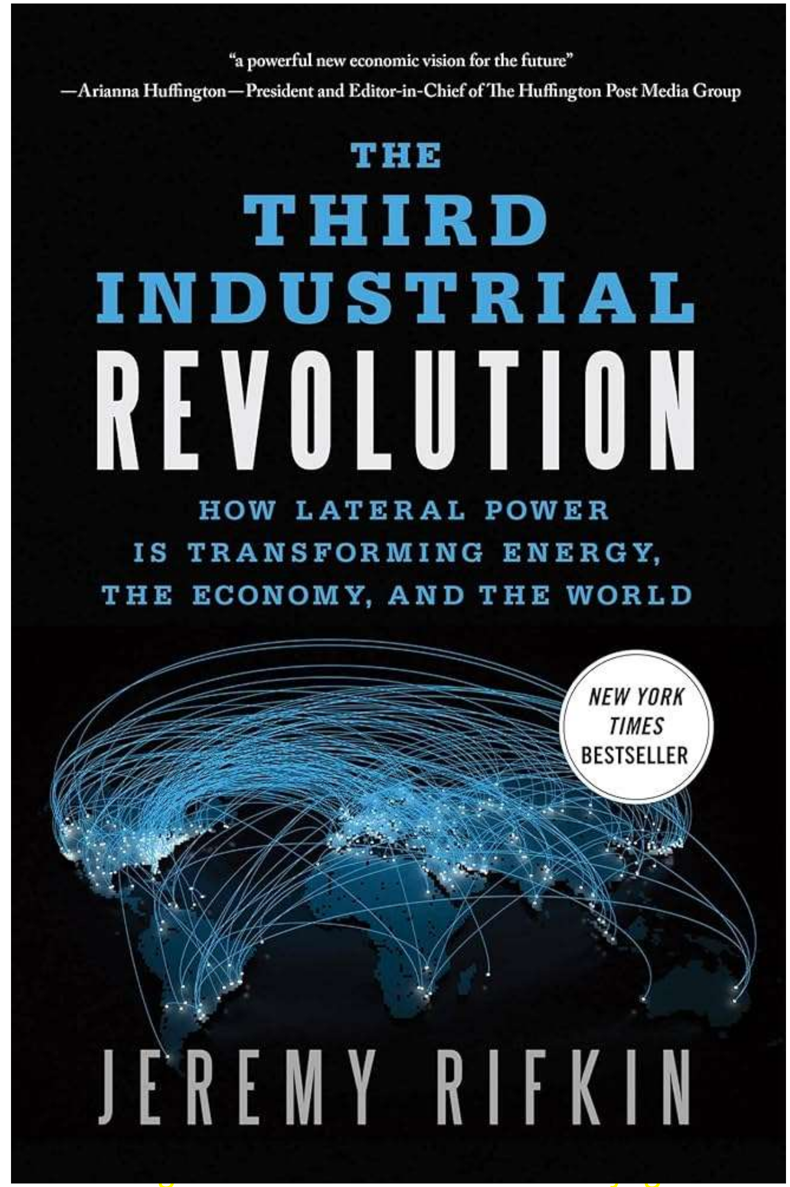
2nd Industrial Revolution (1900s)

Some count the Internet as the 3rd

Rifkin considers the Internet as a continuation of the 2nd IR

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

Viewed as an Internet of energy



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

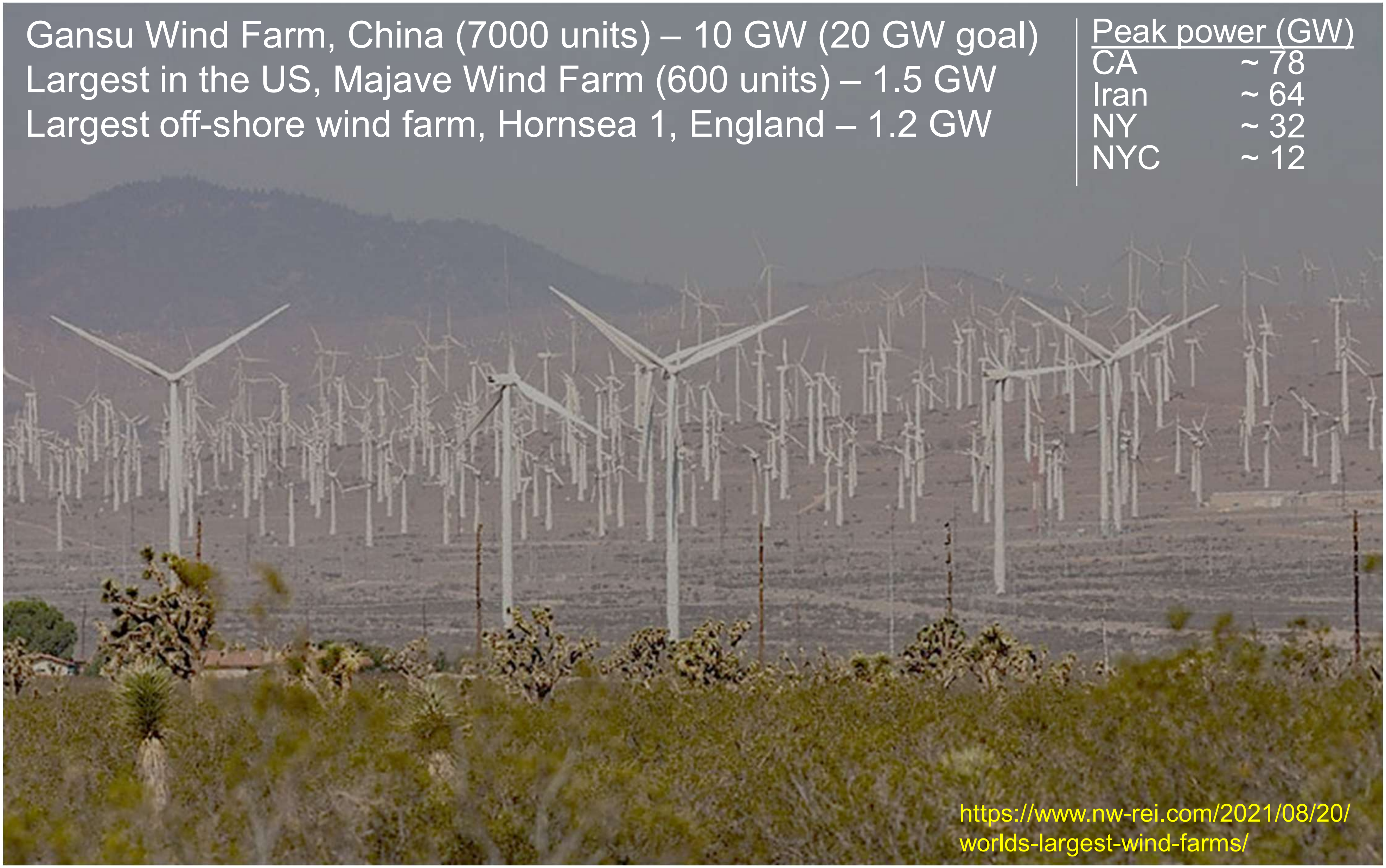
Peak power (GW)	
CA	~ 78
Iran	~ 64
NY	~ 32
NYC	~ 12

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/

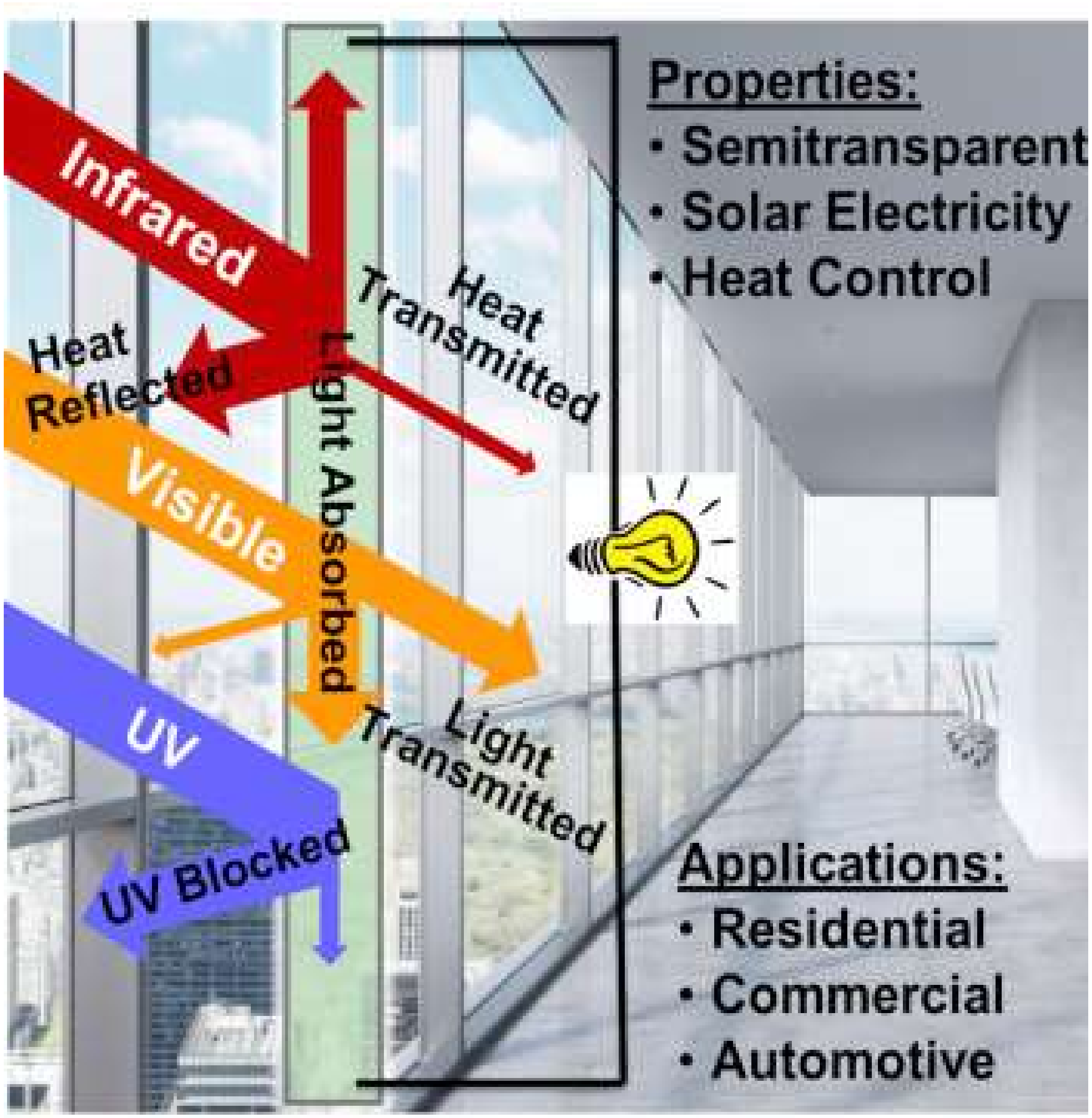
Bricks that Harness & Store Energy

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

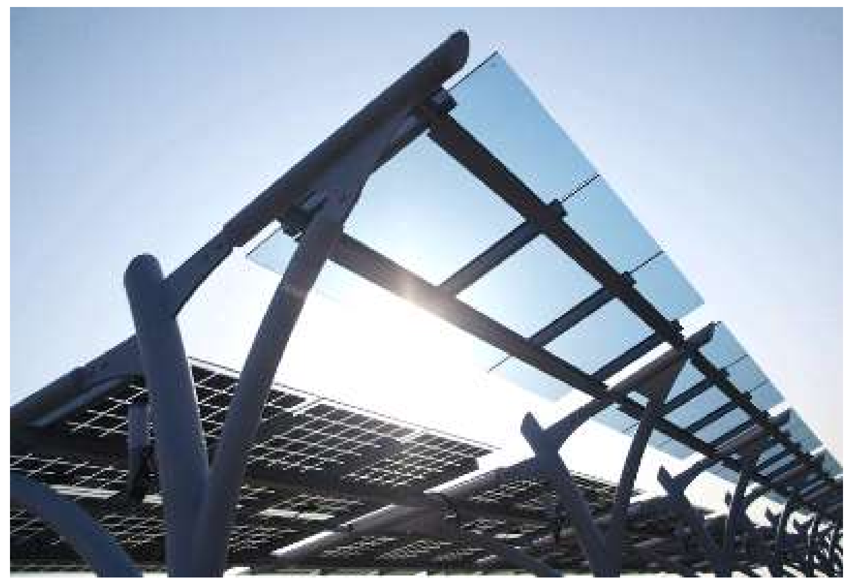


Office towers with glass surfaces can become electricity generators

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)

"Green Premium"

Assume that gasoline costs ~$4.00 per gallon in the US, averaged over several years

If electrofuels cost ~$8.00 per gallon-equivalent (~ x2), then the green premium is $4.00 per gallon

Thinking in terms of the green premium allows us to see where the greatest need for innovation lies

It's possible for green premium to become negative: Then, we have the best of both worlds

In addition to telling us where to invest and innovate, green premiums allow us to use subsidies strategically to direct demand to more desirable alternatives

Fair Calculation of “Green Premium”

In saying that gasoline costs ~$4.00 per gallon in the US, we have ignored the costs of fixing the economic and environmental damage from using gasoline

Fair comparison requires using life-cycle costs

Example: Switching from coal to gas cuts emissions by 50%
But if we want to aim for net-zero in 25 years …
the new gas-powered plants won’t depreciate by then


May 2008
The Cost of Climate Change
NRDC
The Earth's Best Defense
What We’ll Pay if Global Warming Continues Unchecked

Natural Resources Defense Council: https://www.nrdc.org/sites/default/files/cost.pdf

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

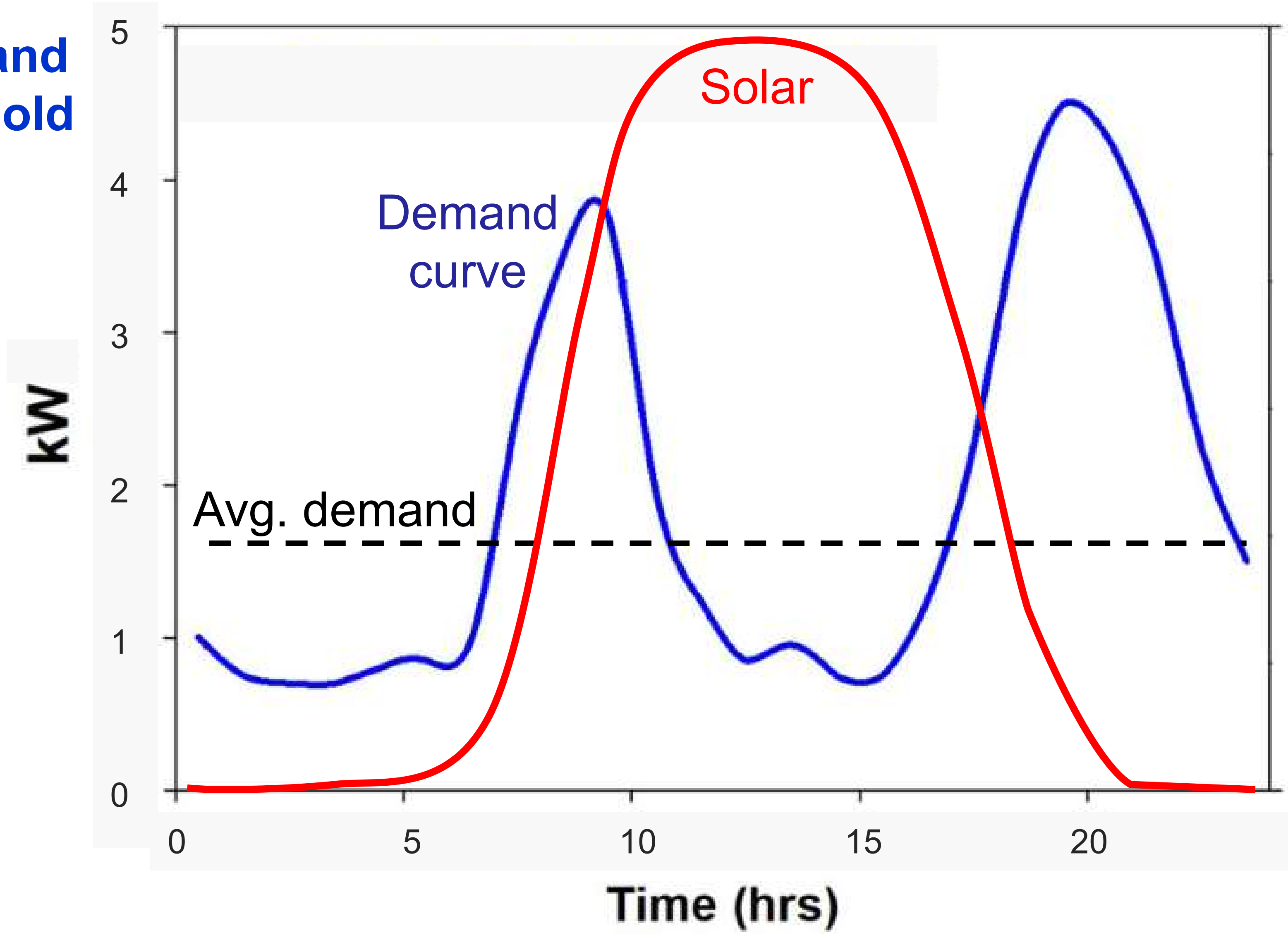
5 kW when the sun shines
6 hours on average ~ 30 kWh

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)

Household Power Demand Variation

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



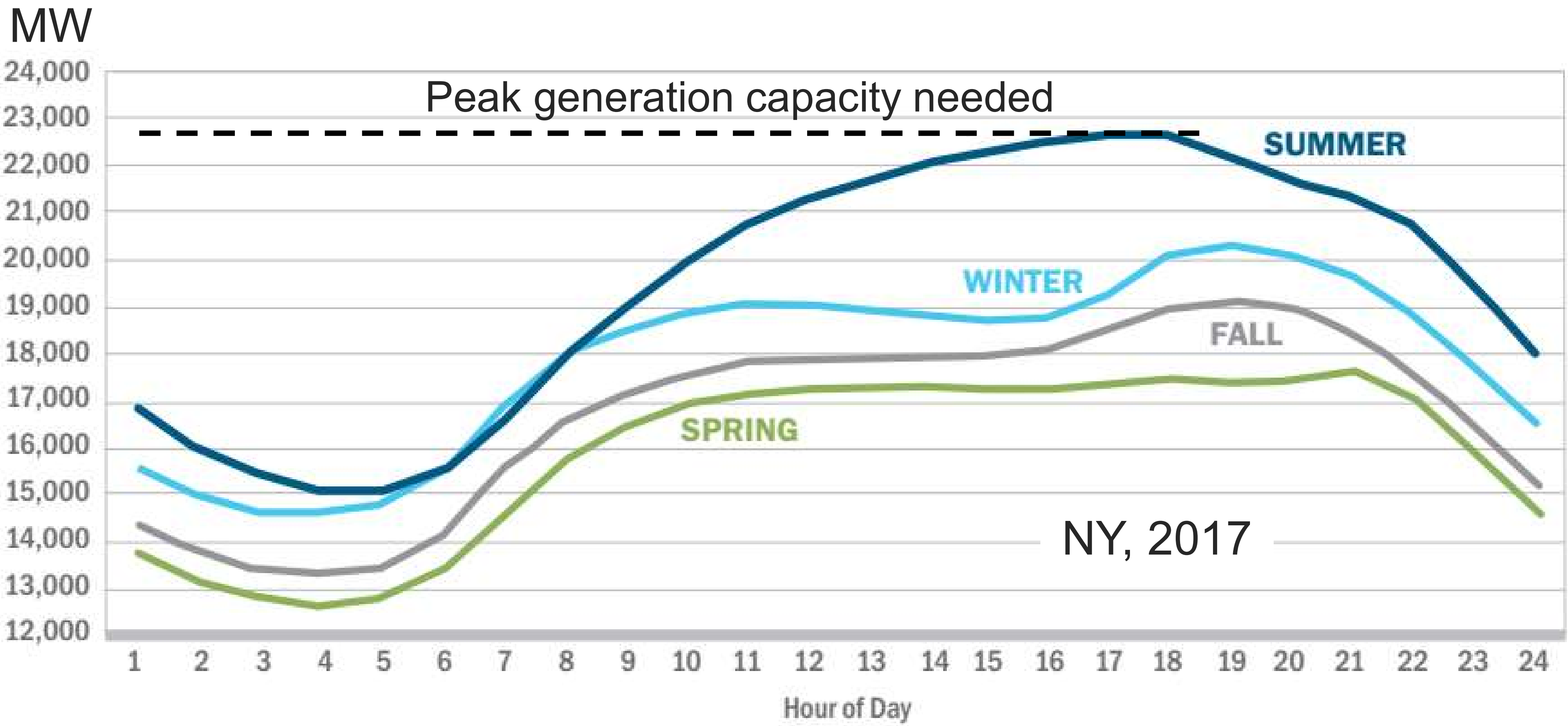
Solar supply
~ 5.0 kW peak
~ 30 kWh / day
~ 11 MWh / year

City Power Demand Variations

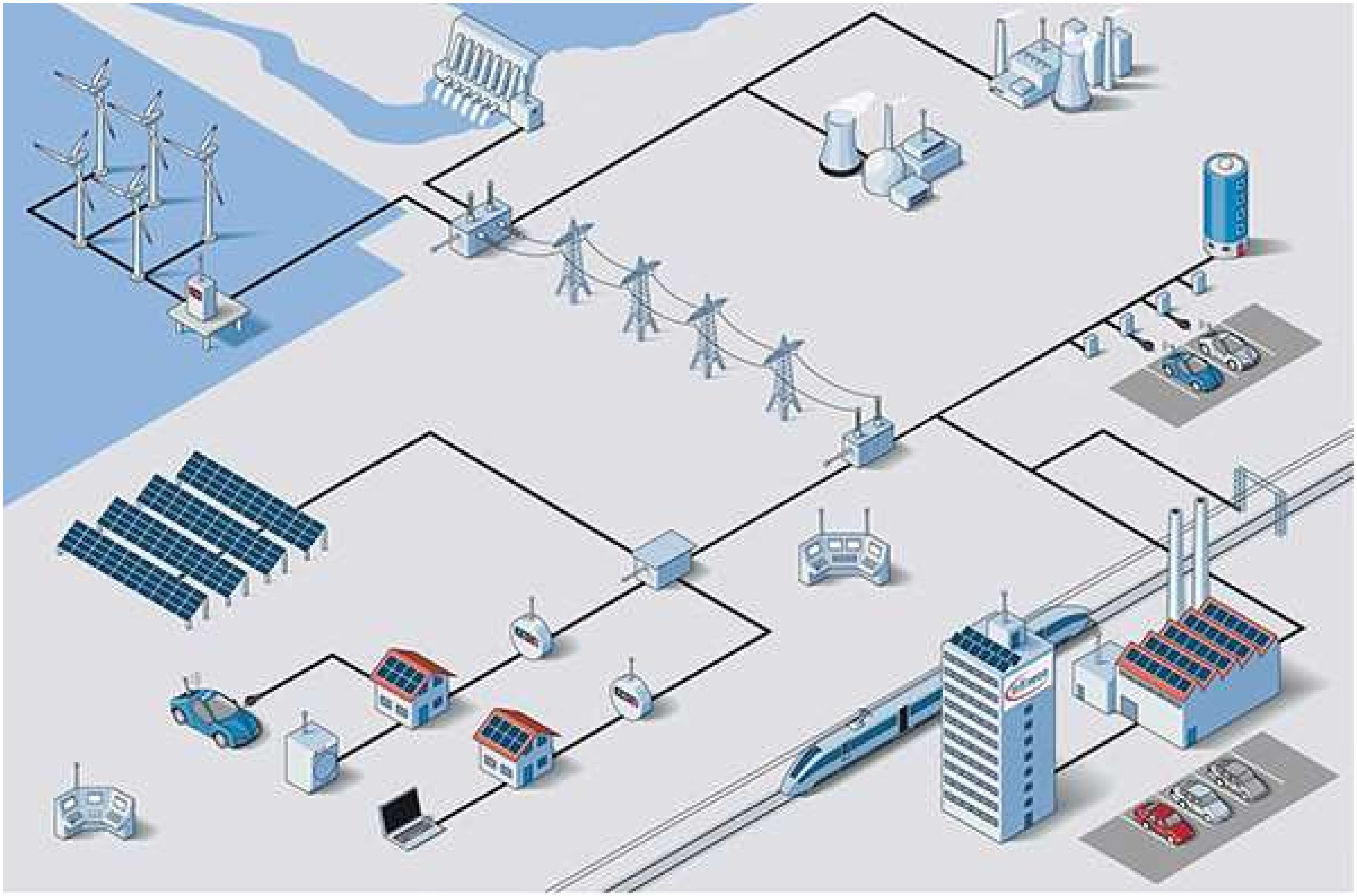
Demand has seasonal, daily, and hourly variations

Fluctuations a function of weather, weekday, business hours, etc.

Places with hot summers have higher peaks in summer due to A/C load

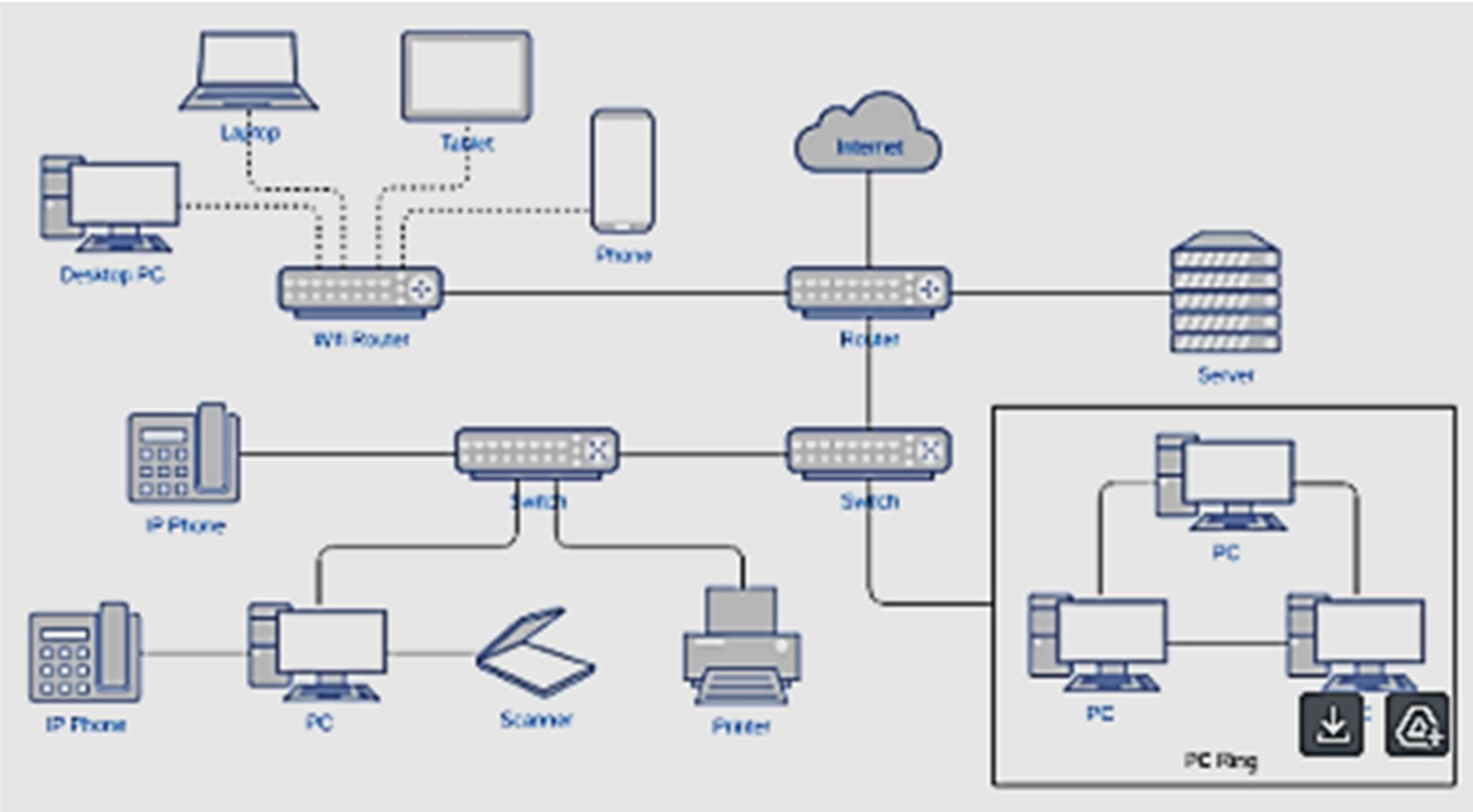


Grid Energy Generation and Storage



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

Internet Data Generation and Storage



Power-Hungry Data Centers

Rapidly-expanding use of energy-intensive AI applications

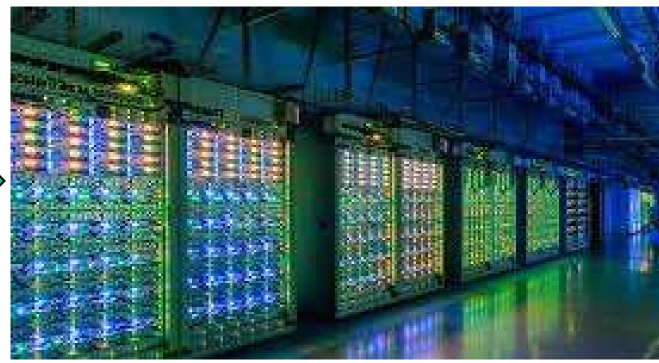
Data-center operators are working on multiple fronts to reduce their energy requirements and to gain access to reliable energy supplies, up to and including building nuclear power plants nearby

Why Energy Storage?

Energy production

Energy consumption

Data production

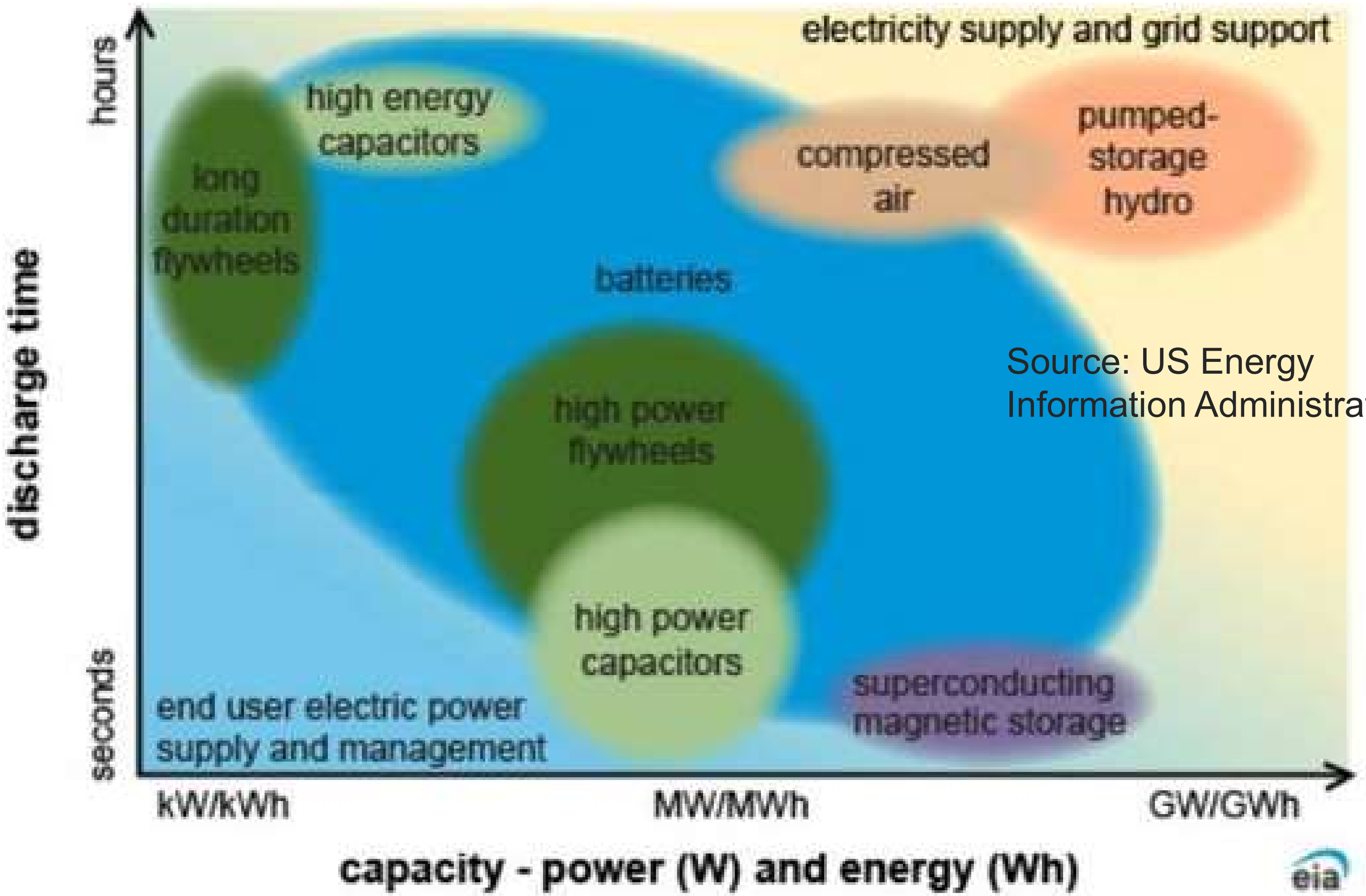


Data consumption

Crop production

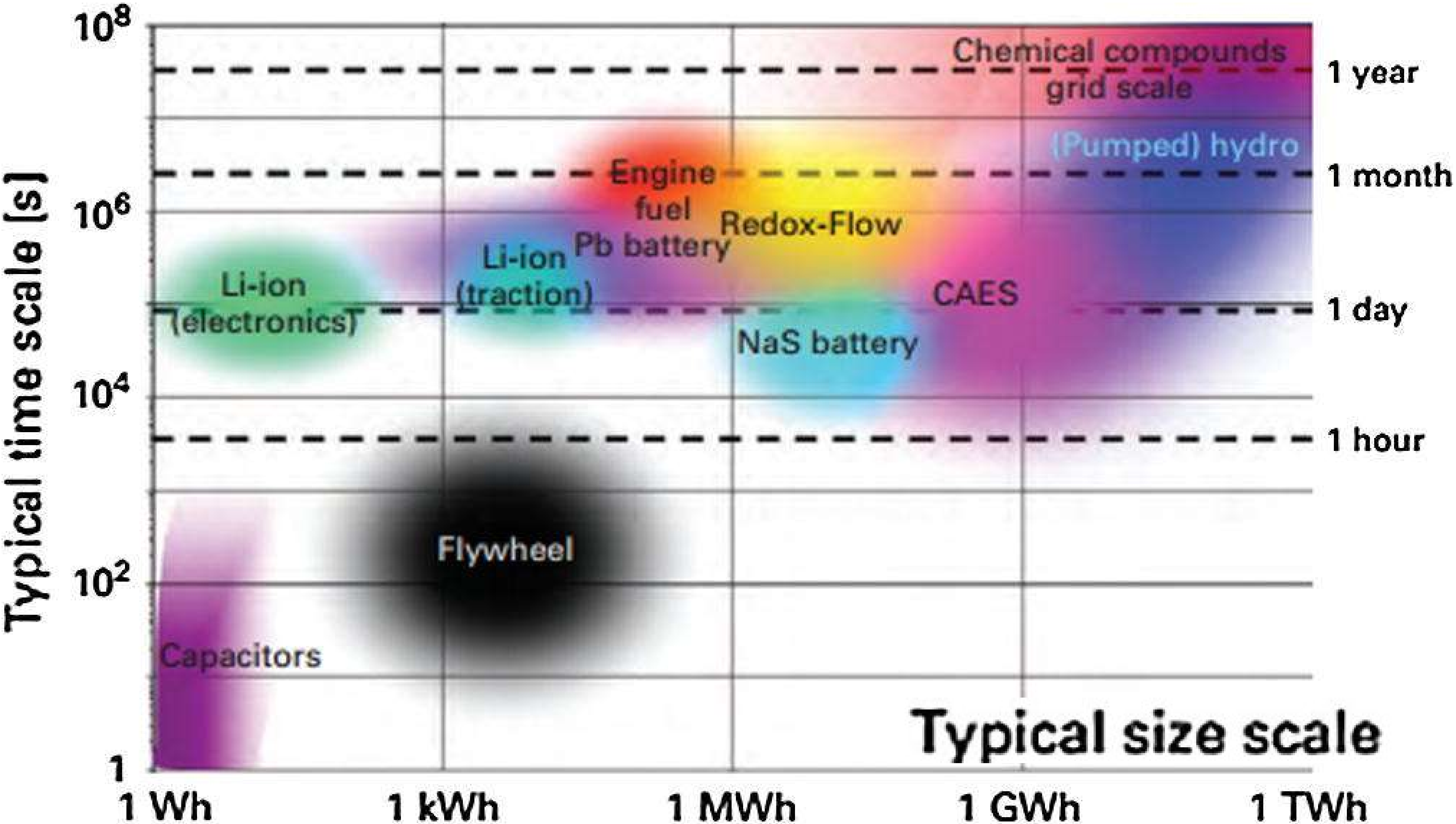
Crop consumption

Attributes of Energy Storage Methods



Source: US Energy Information Administration

The Range of Energy Storage Options



Options for Storing Electrical Energy

Mechanical

Flywheel; Pumped hydro; Gravity
Compressed air; Liquid piston

Chemical

Hydrogen; Biofuel; Biodiesel

Electrochemical

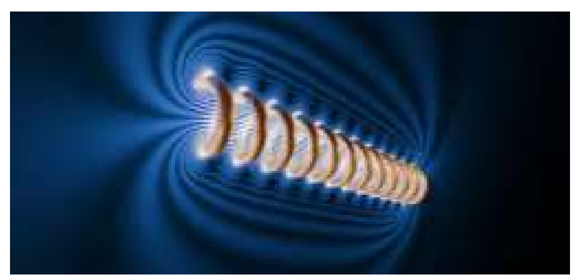
Supercapacitors; Batteries

Superconducting

Magnetic

Cryogenic

Liquid air



Flywheel Energy Storage

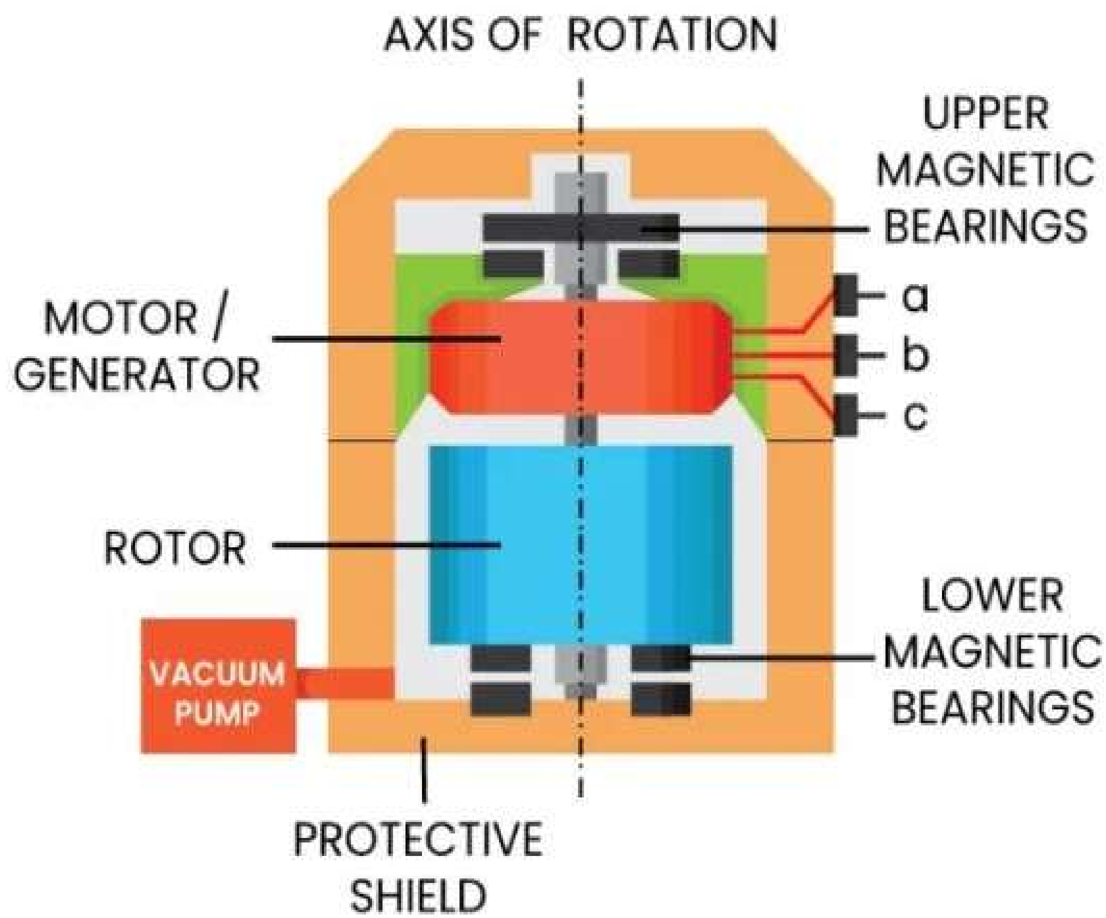
Older generation used a steel flywheel rotating on mechanical bearings

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

Magnetic bearings and high vacuum, yield ~85% round-trip efficiency

Capacities: 3-133 kWh

Charging: < 15 minutes



Flywheel: Old, Proven Technology

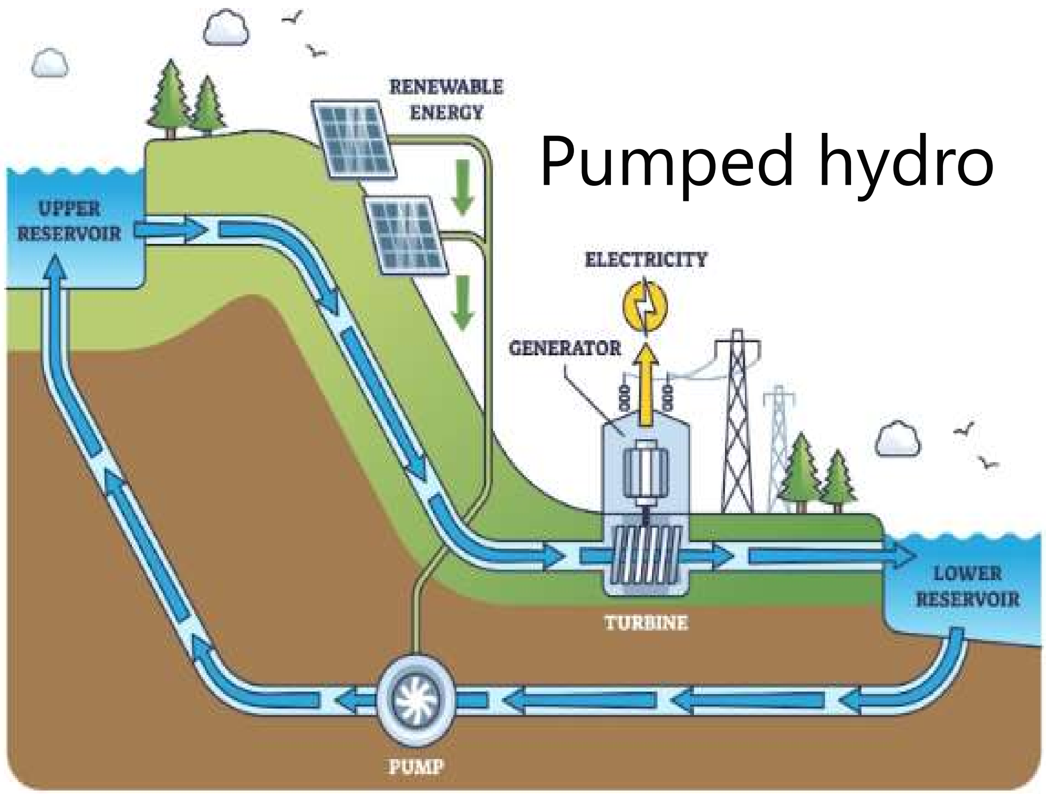
Power plant with flywheels

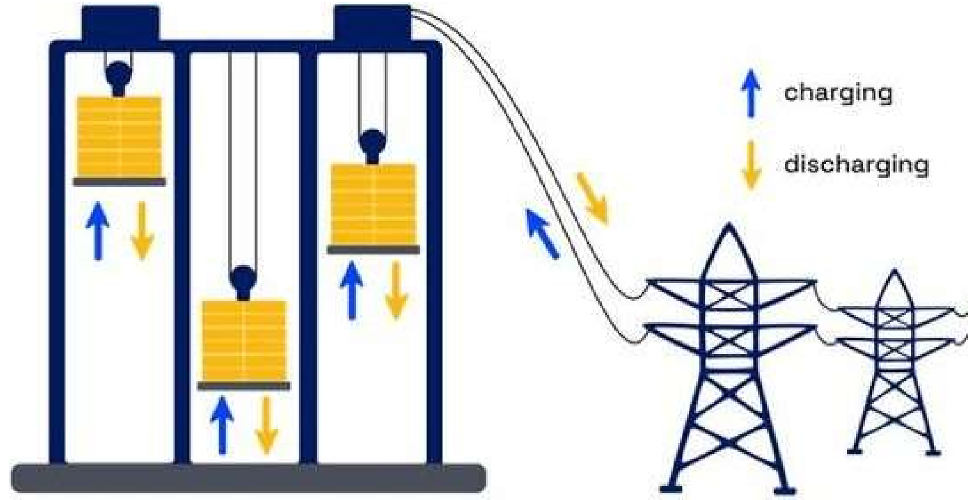
Gravity Energy Storage

Round-trip efficiency can be as high as 86%

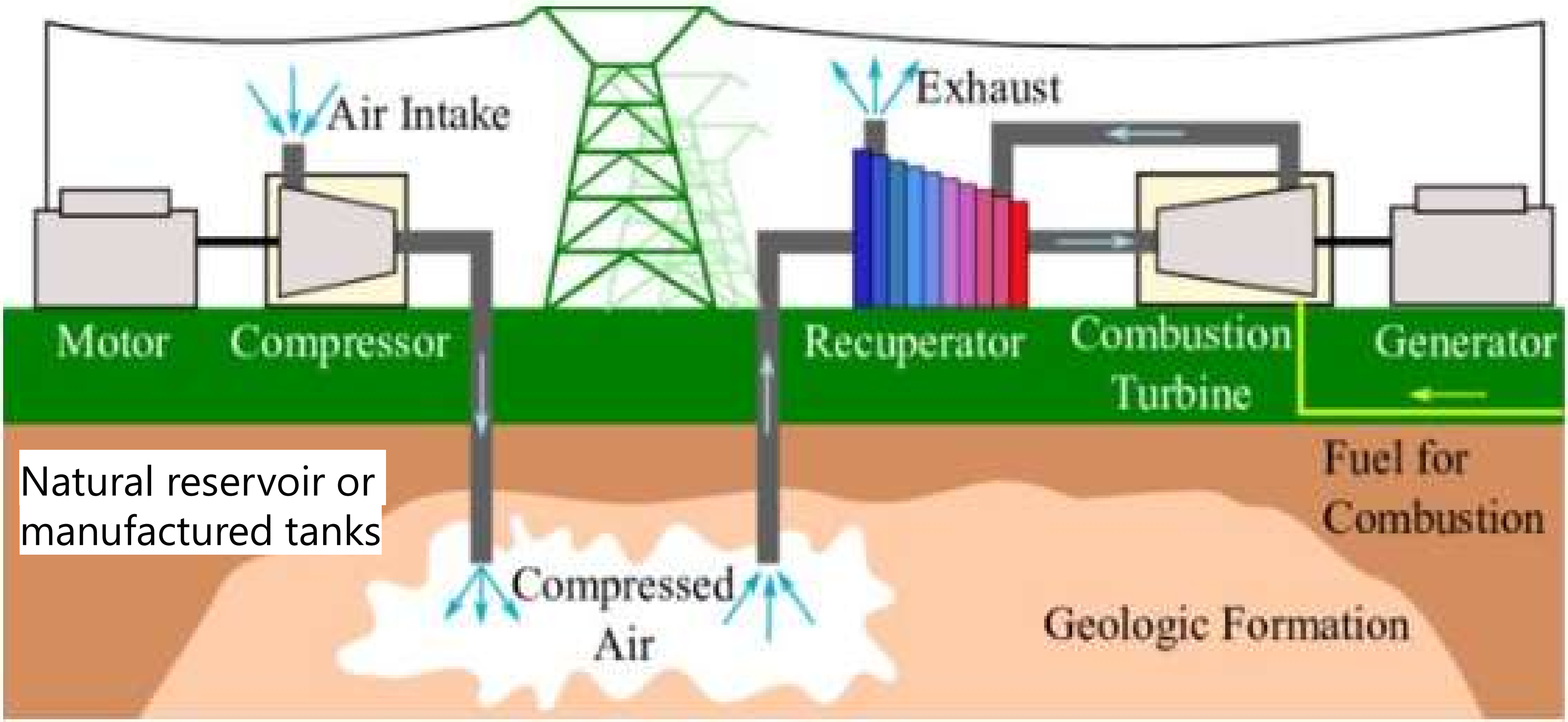
https://www.youtube.com/watch?v=NhGECJTvDrc

Pumped hydro





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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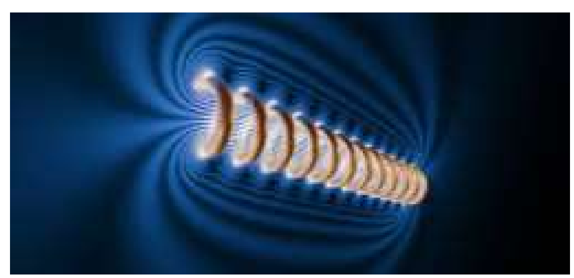
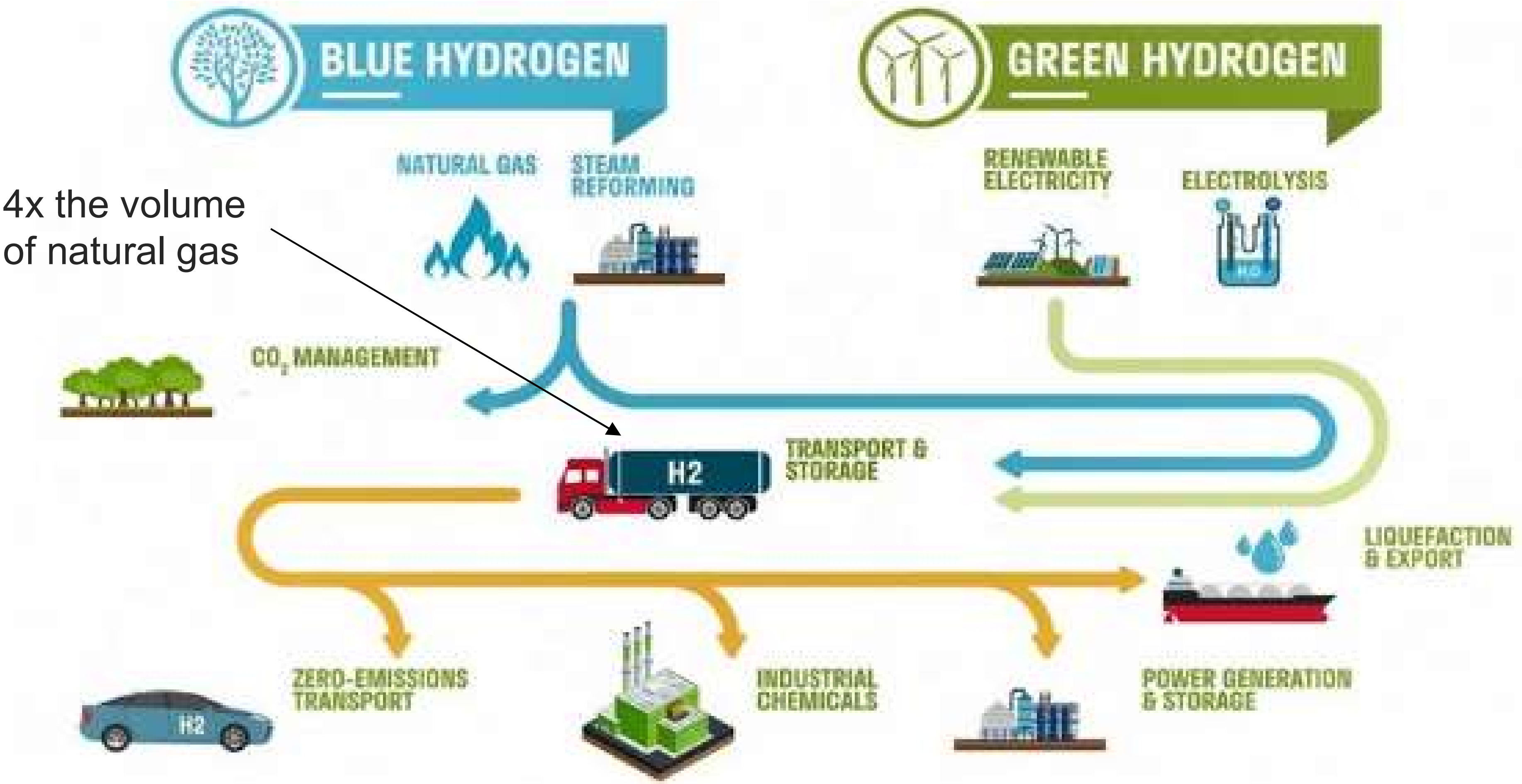


Green Hydrogen

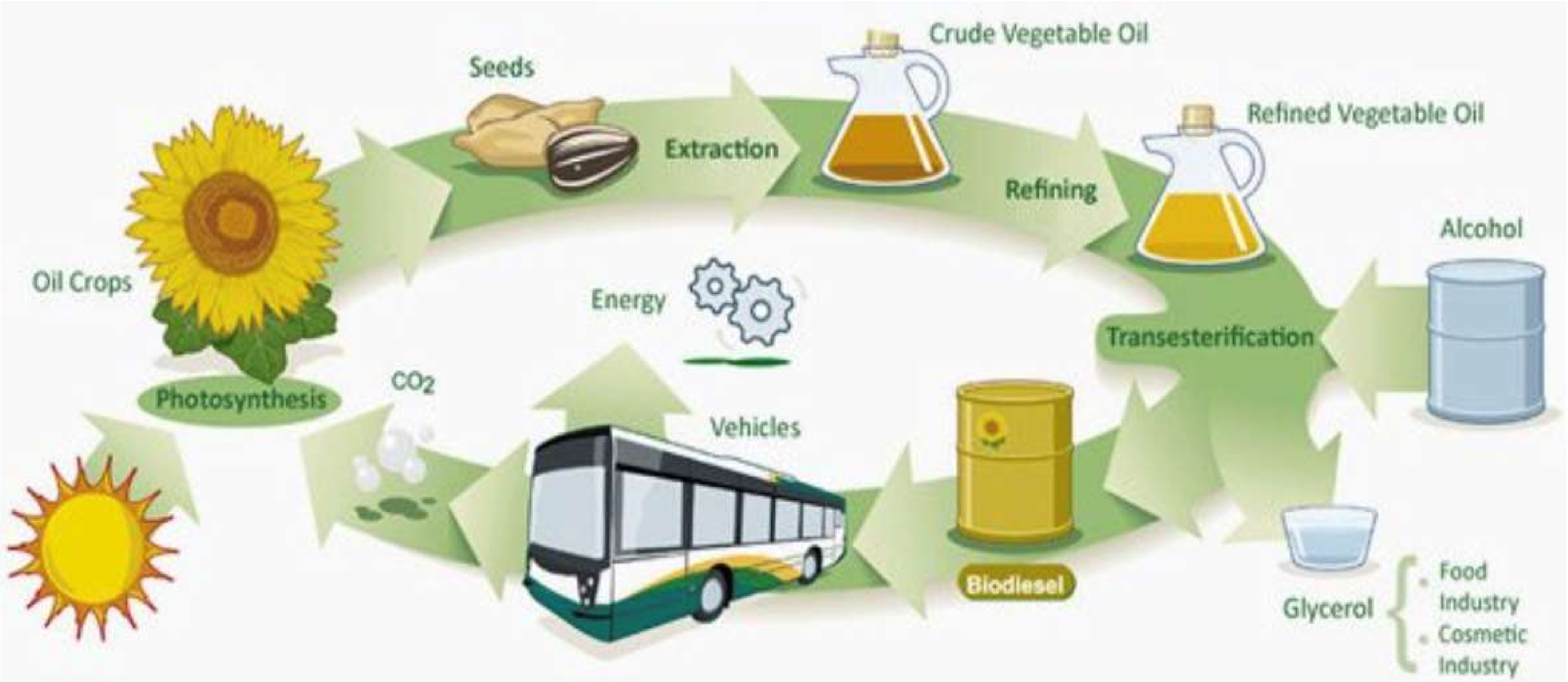
4x the volume of natural gas



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/

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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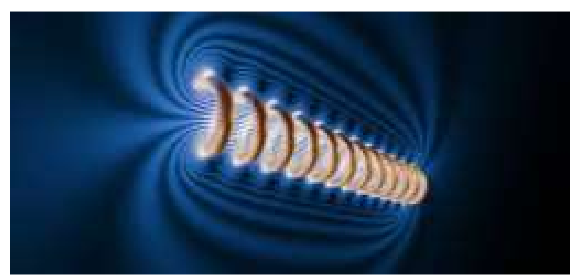
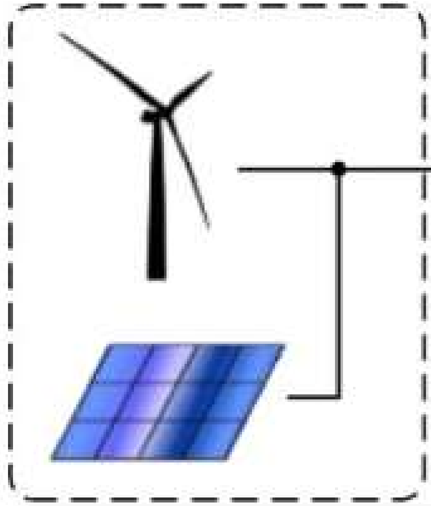
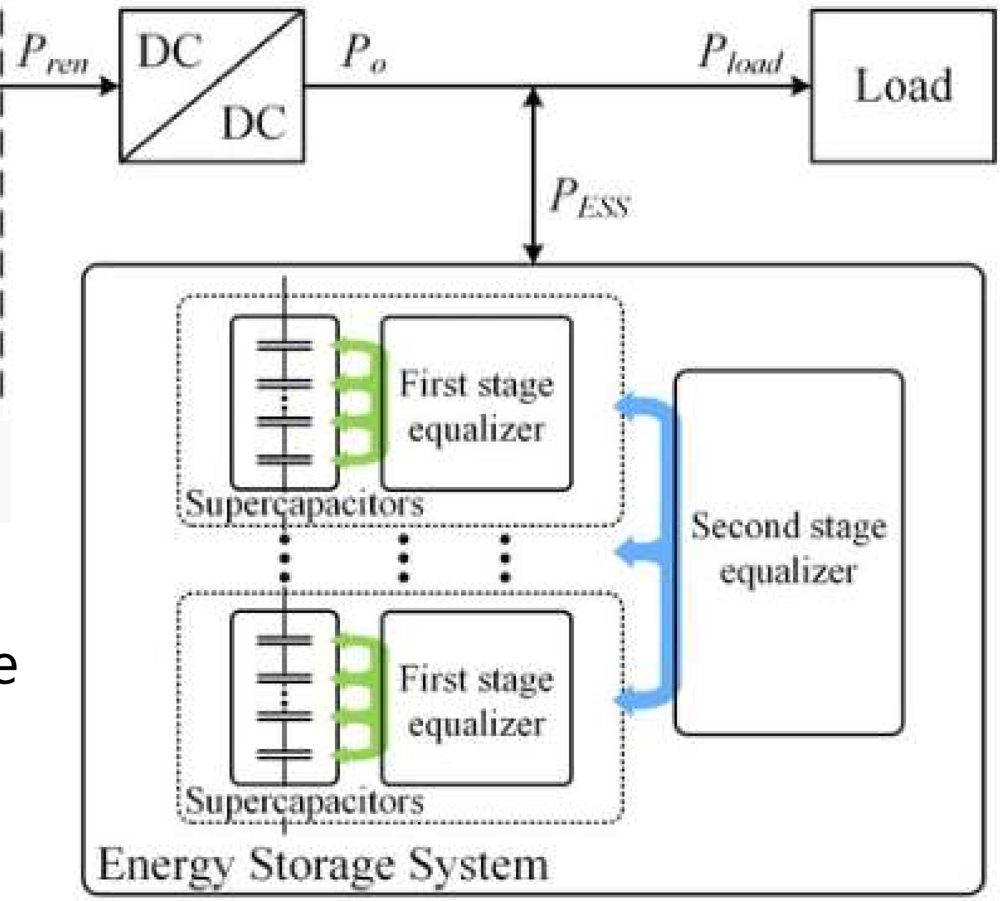



Supercapacitors for Energy Storage

Renewable
Power
Sources



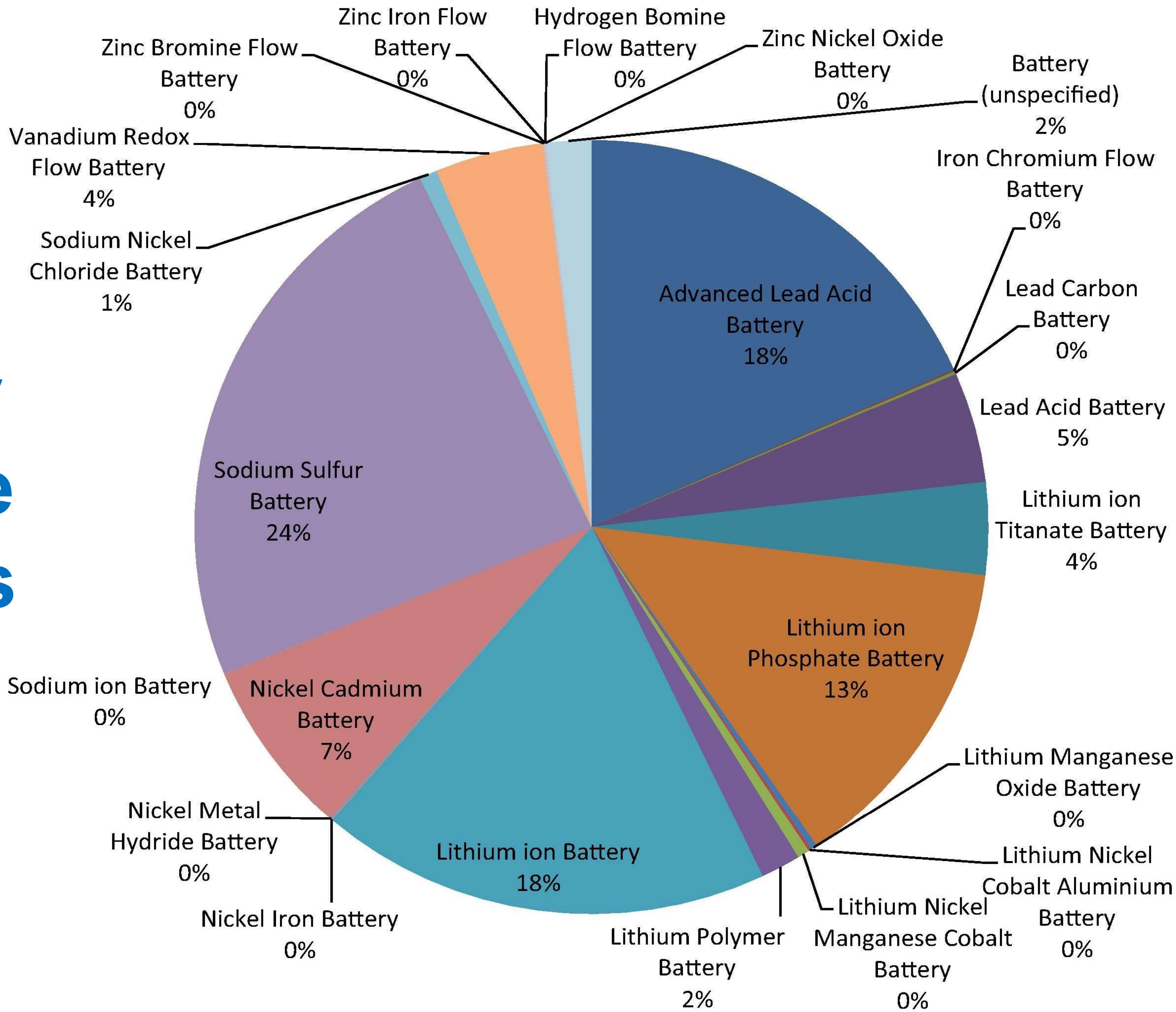


Capacitors: Higher power density, rapid charge/discharge

Batteries: Higher energy density per volume or weight

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

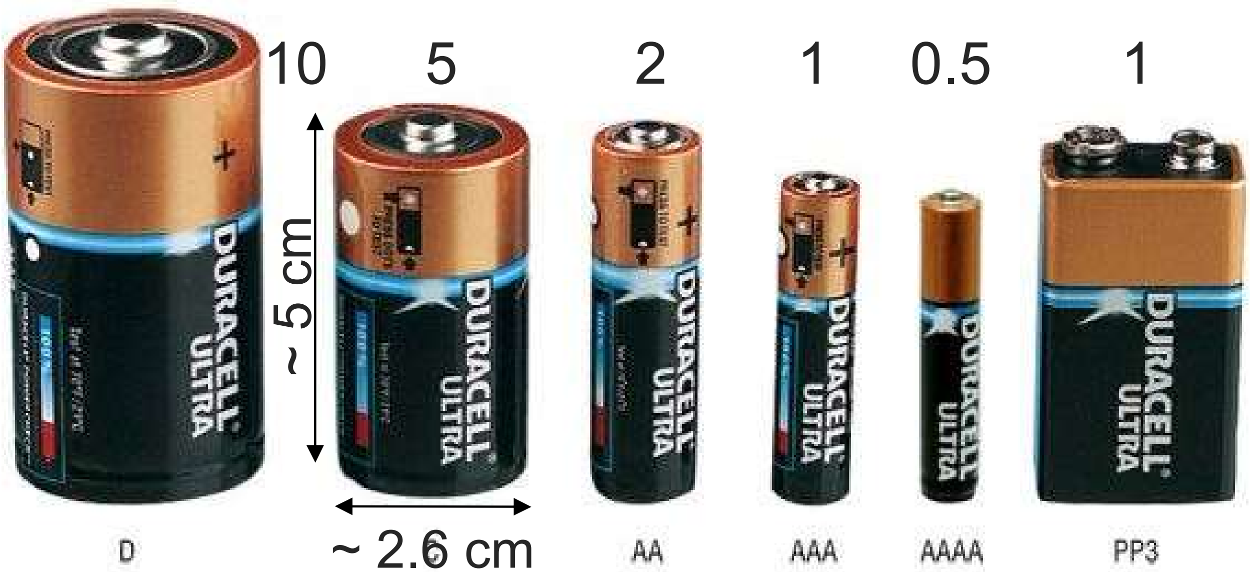
Battery Storage Options



Battery Voltage, Capacity, and Power

10 5 2 1 0.5 1 Ampere-hours

~ 5 cm



~ 2.6 cm

Tesla batteries on-line

~ 2 cm

~ 7 cm

~ 5K-10K cells

Tesla Power Wall: Another Look

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

Solar-cell production
- 5 kW when the sun shines
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Tesla Power Wall 3 (~$8500)
- Fridge size: 110 x 60 x 18 cm; 130 kg
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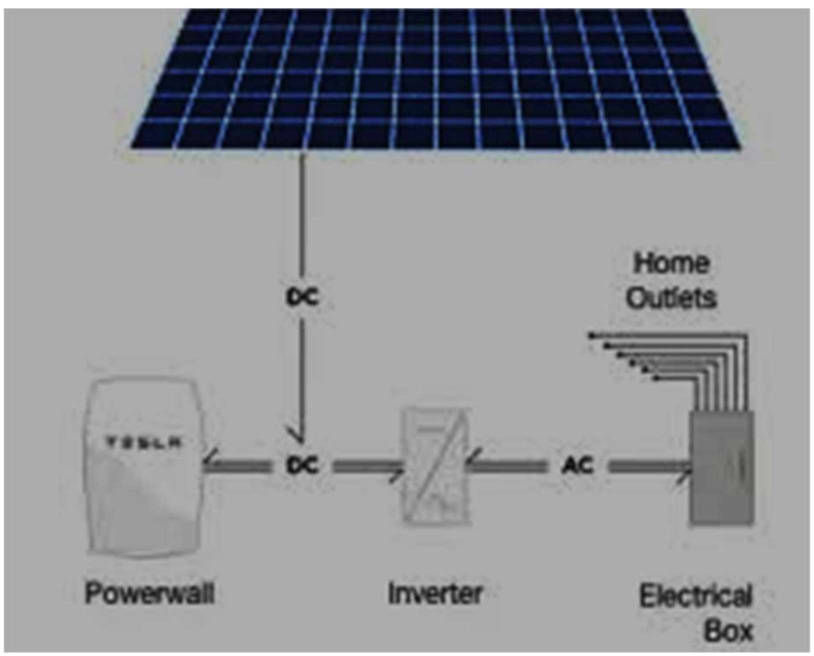

World's Largest Battery Installation

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

Options for Storing Electrical Energy

Mechanical

Flywheel; Pumped hydro; Gravity
Compressed air; Liquid piston

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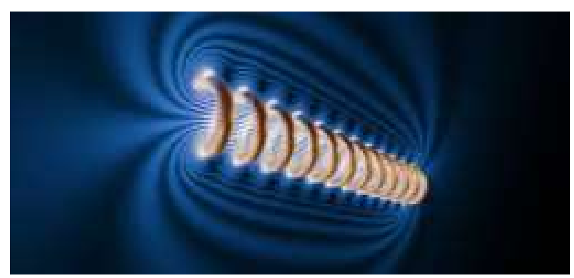
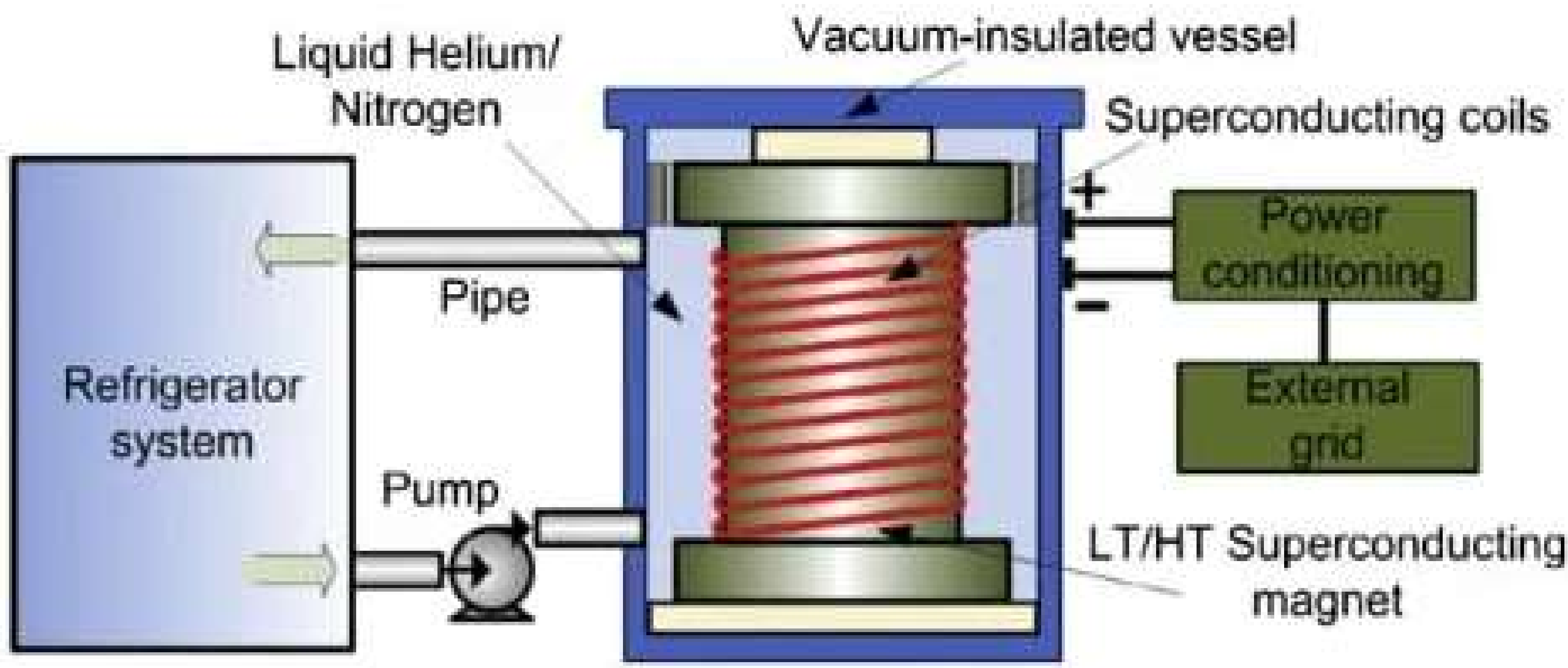


Superconducting Magnetic Storage

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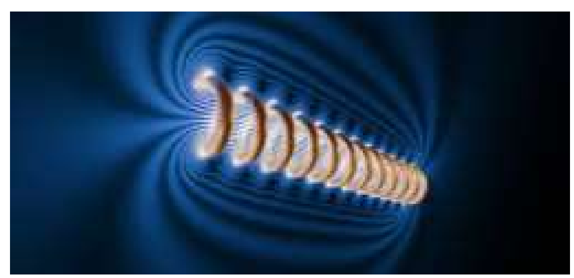


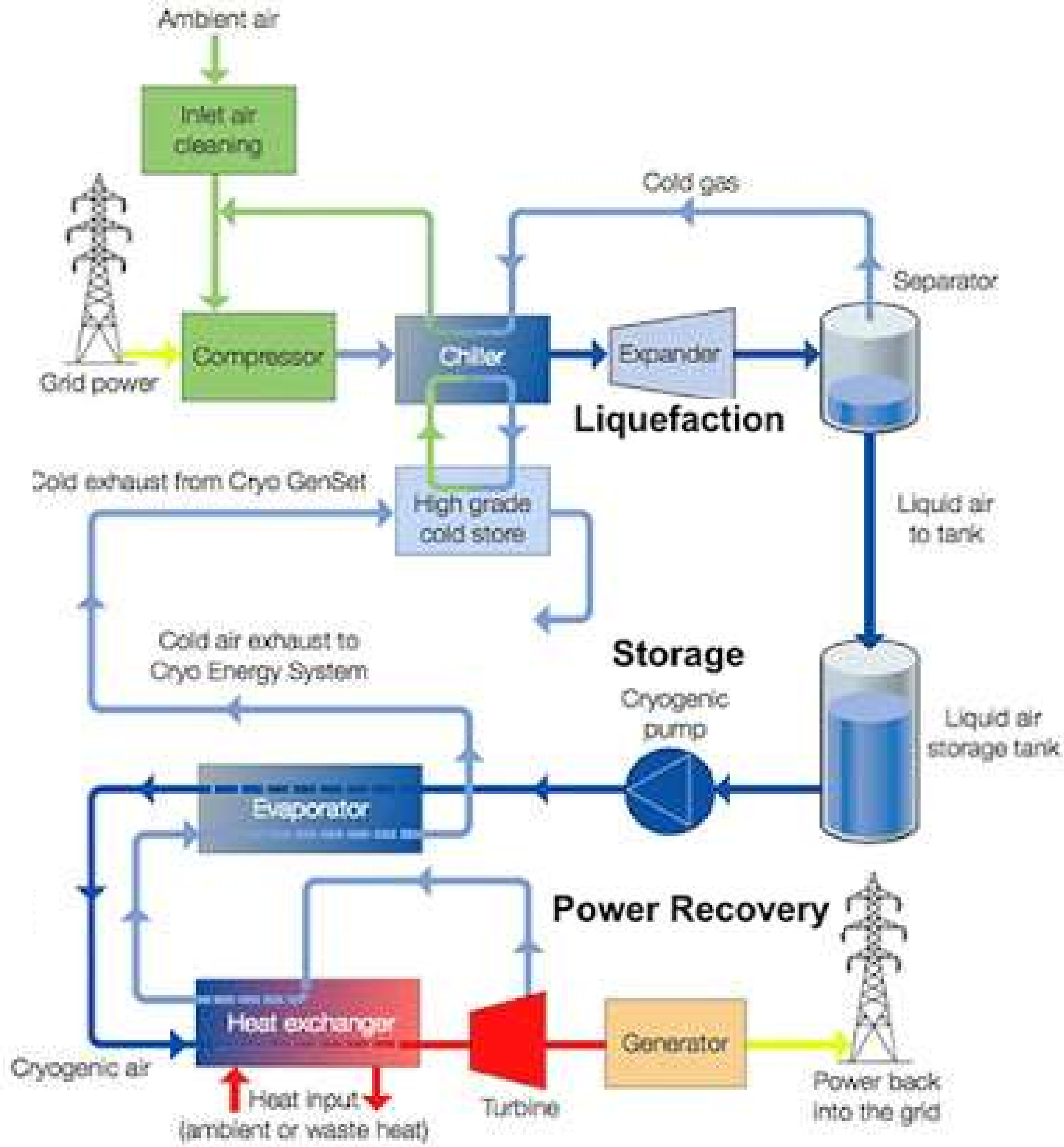
Cryogenic Liquid-Air Storage

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

Cost: $200-530/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)

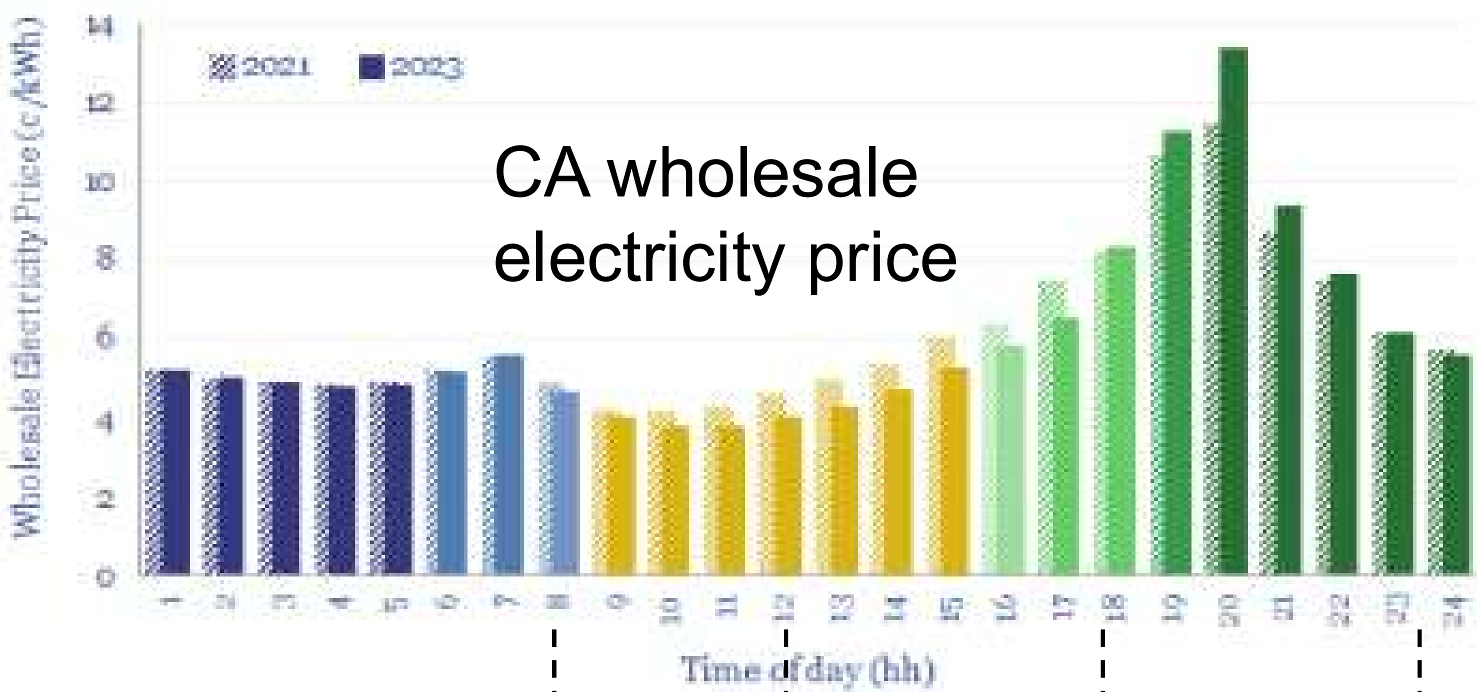
A summary of the rollout of smart meters in selected countries. (Data for Australia and US from 2023, Canada, China, Japan and UK from 2022, and Sweden, Estonia and Denmark from 2020. DSO = distribution service operator, IESO = independent electricity system operator) Rui Yuan et al 2024,

Power delivered

Power received

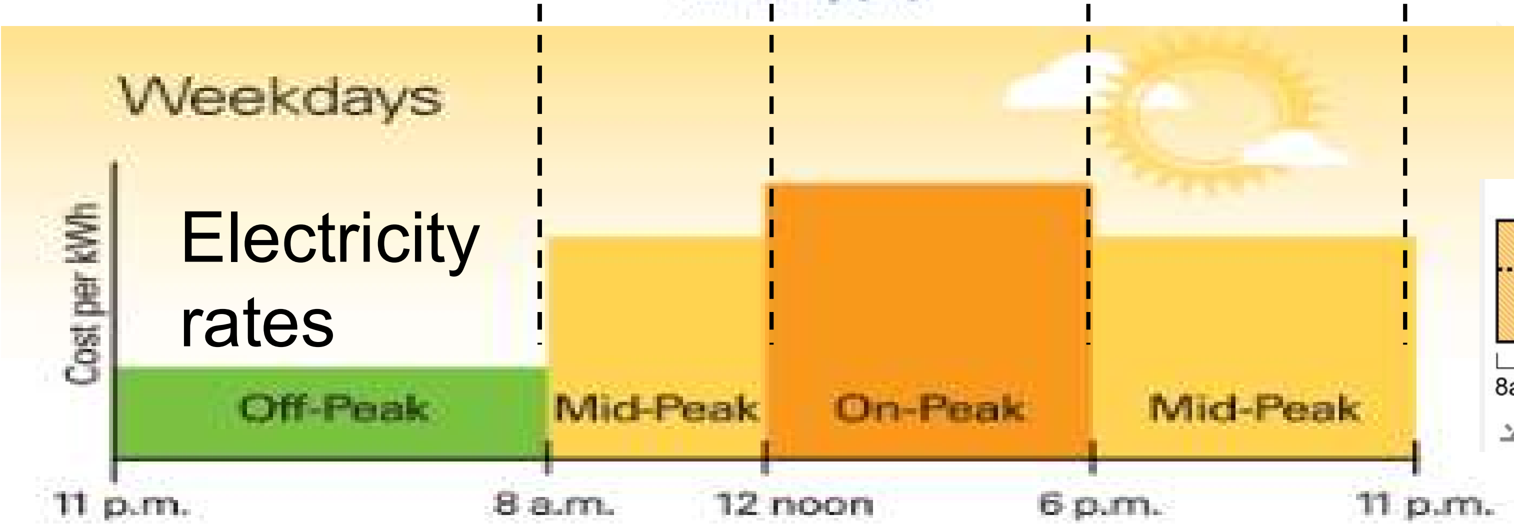
Net difference

Differential Pricing of Electric Power



CA wholesale electricity price

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



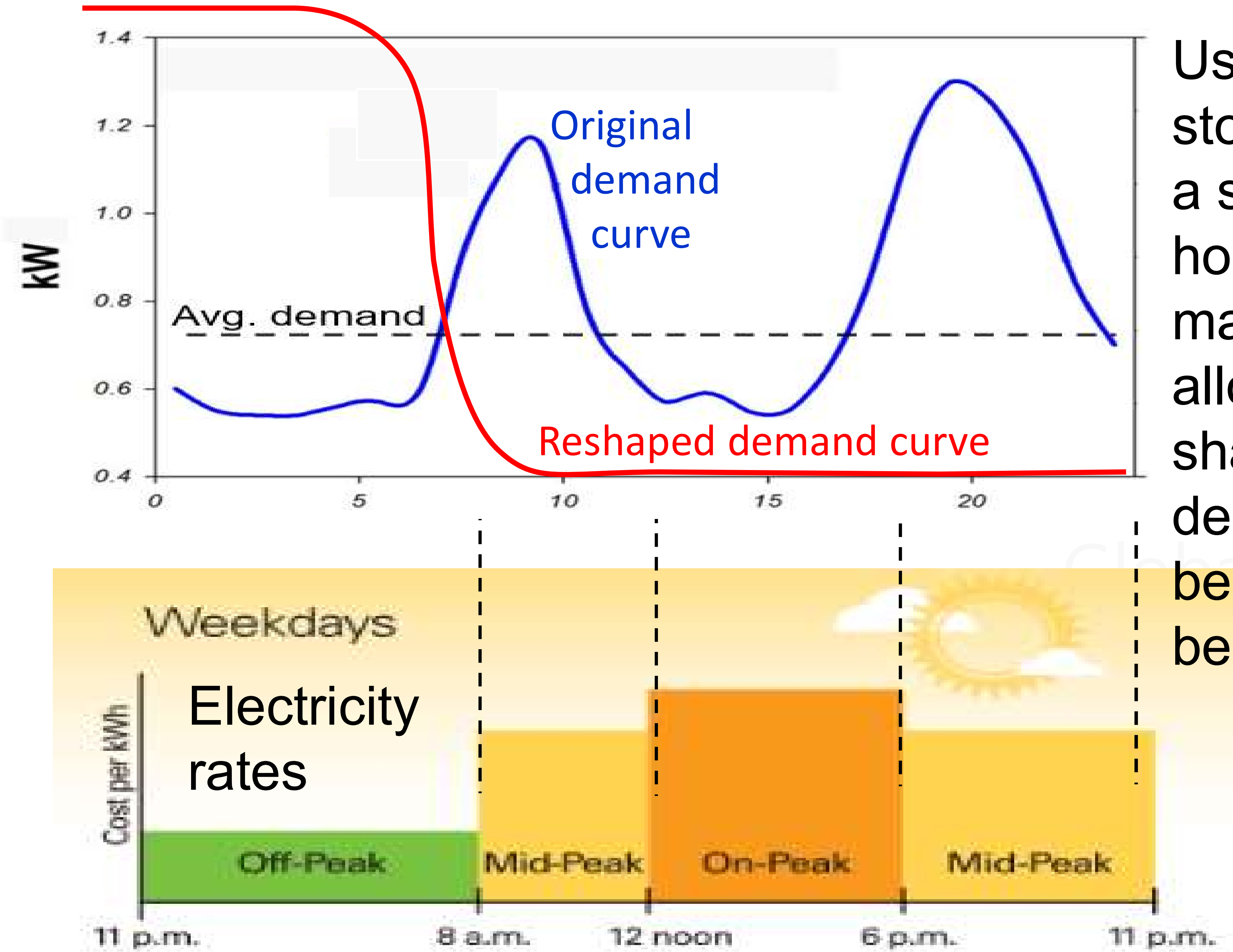
Electricity rates

Sample Edison pricing

Weekdays

8am–4pm	4pm–9pm	9pm–8am	
37¢	60¢	37¢	Above Baseline
27¢	50¢	27¢	After Baseline Credit

Shaping Your Demand Curve



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

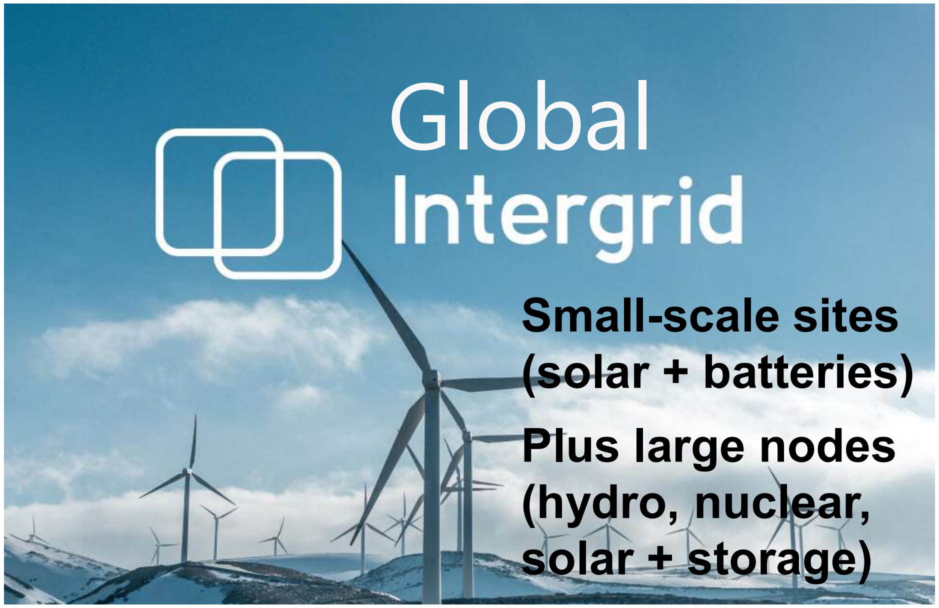
Conclusion

An Internet (Intergrid) of energy is quite practical

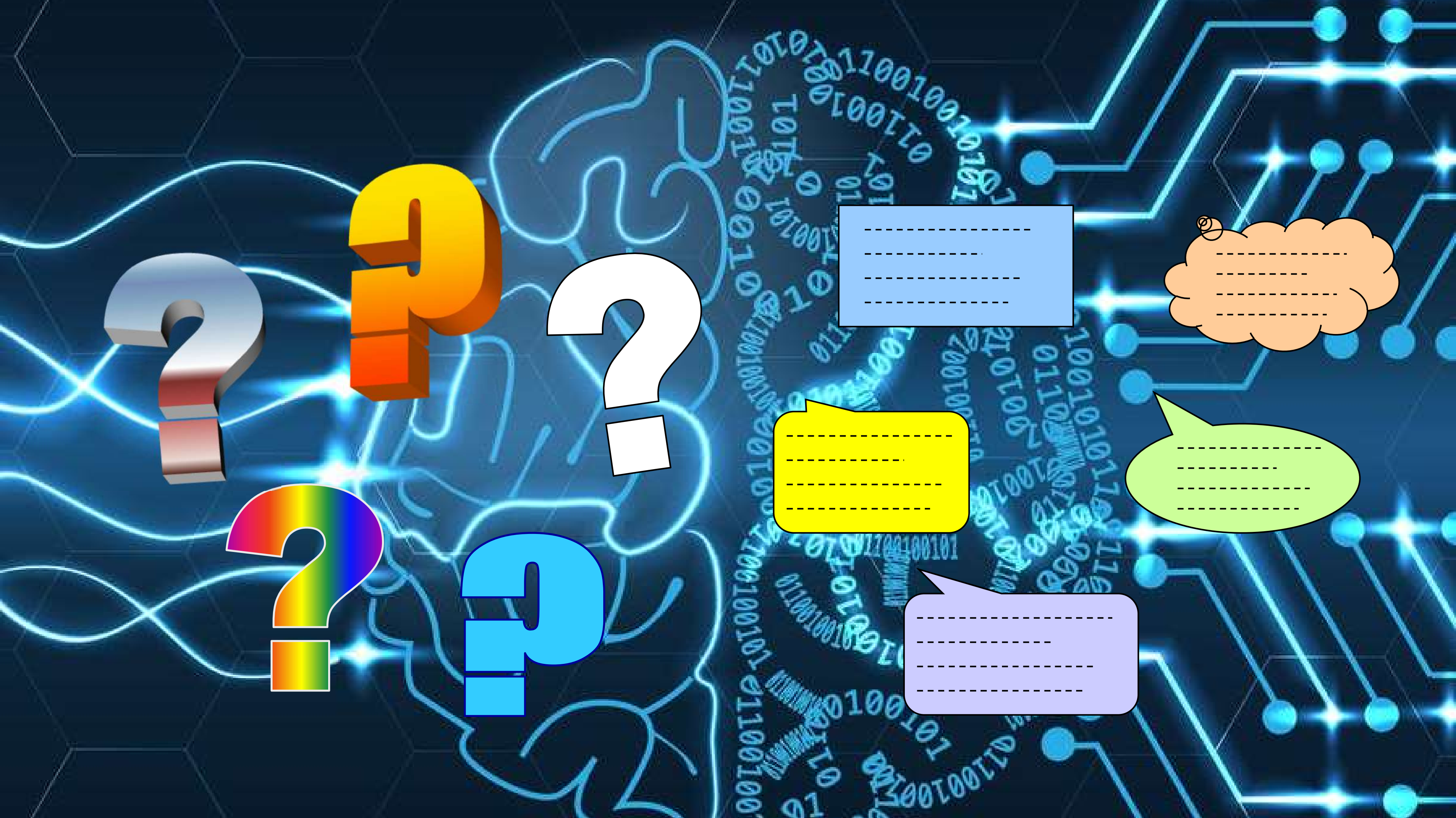
Grid energy prices going up and renewable energy becoming cheaper will lead to a crossover point (already reached?)

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



Questions or Comments?



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

Energy Storage Technologies to Facilitate the U seof Renewable Energy

Renewable energy is gradually becoming cost-competitive, as we invest more in developing new production and storage technologies. The storage part is critical and needs significantly more effort. Production levels of renewable energy, solar and wind in particular, tend to be variable. Such supply variations, combined with natural variations in demand, give rise to the need for storing energy, in much the same way that we store grains in silos to smooth out the variations in when & where they are produced and when & where they are needed. In the case of grains, even year-to-year variations due to weather, pests, and natural disasters can be tolerated with sufficient storage capacity. There is no reason why similar smoothing methods cannot be used for energy. The fact that we have not been investing more in developing energy-storage technologies is a direct result of the "low cost" of energy derived from oil, gas, & coal and the exorbitantly-funded campaign by the fossil-fuel industry to brand renewable energy as "expensive." However, most cost comparisons are unfair, because they ignore environmental and other indirect costs. Mitigating the effects of harmful emissions from burning fossil fuels is rather expensive, a figure we should include in their life-cycle cost. If we do so, the so-called "green premium" will vanish or even become negative.