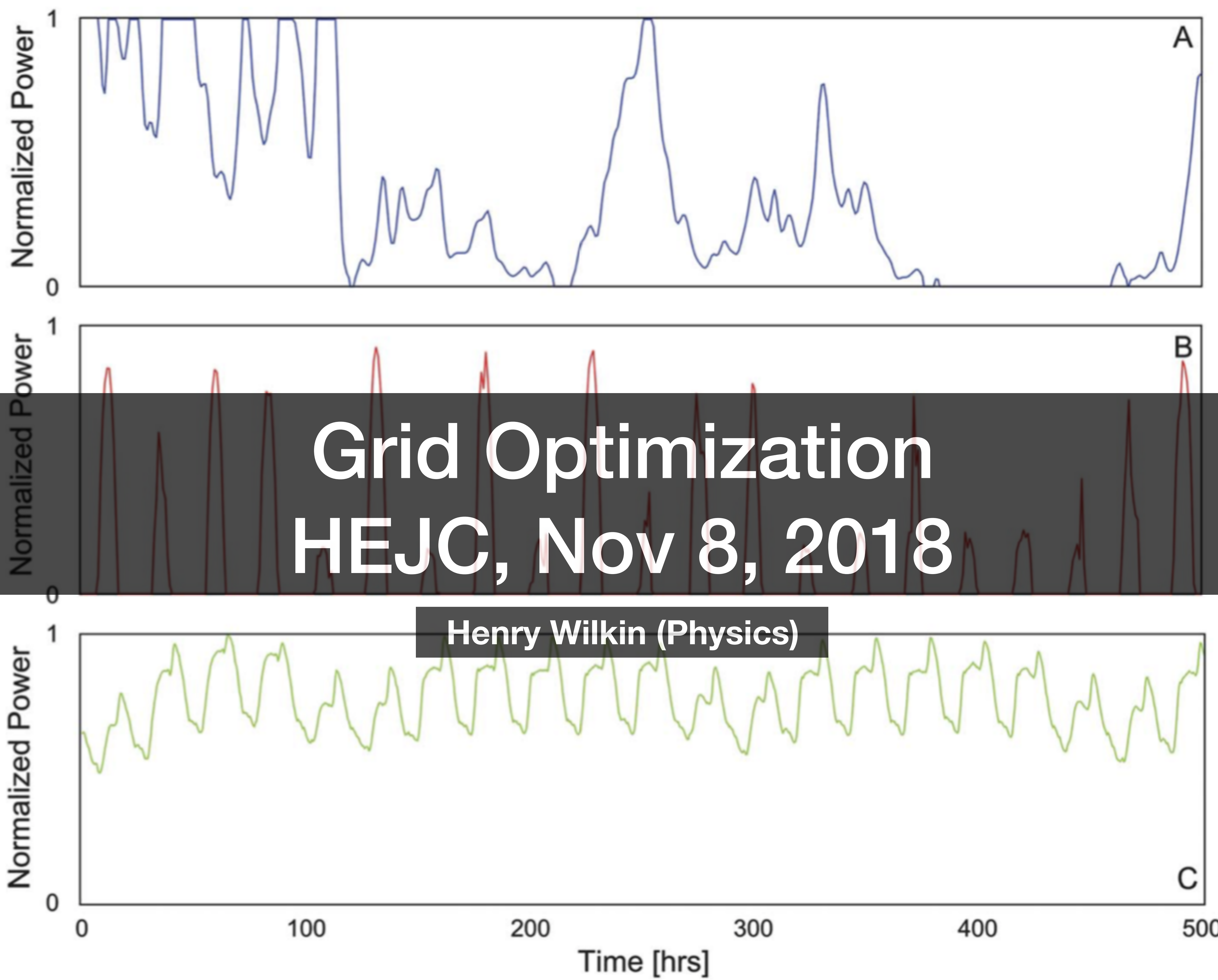
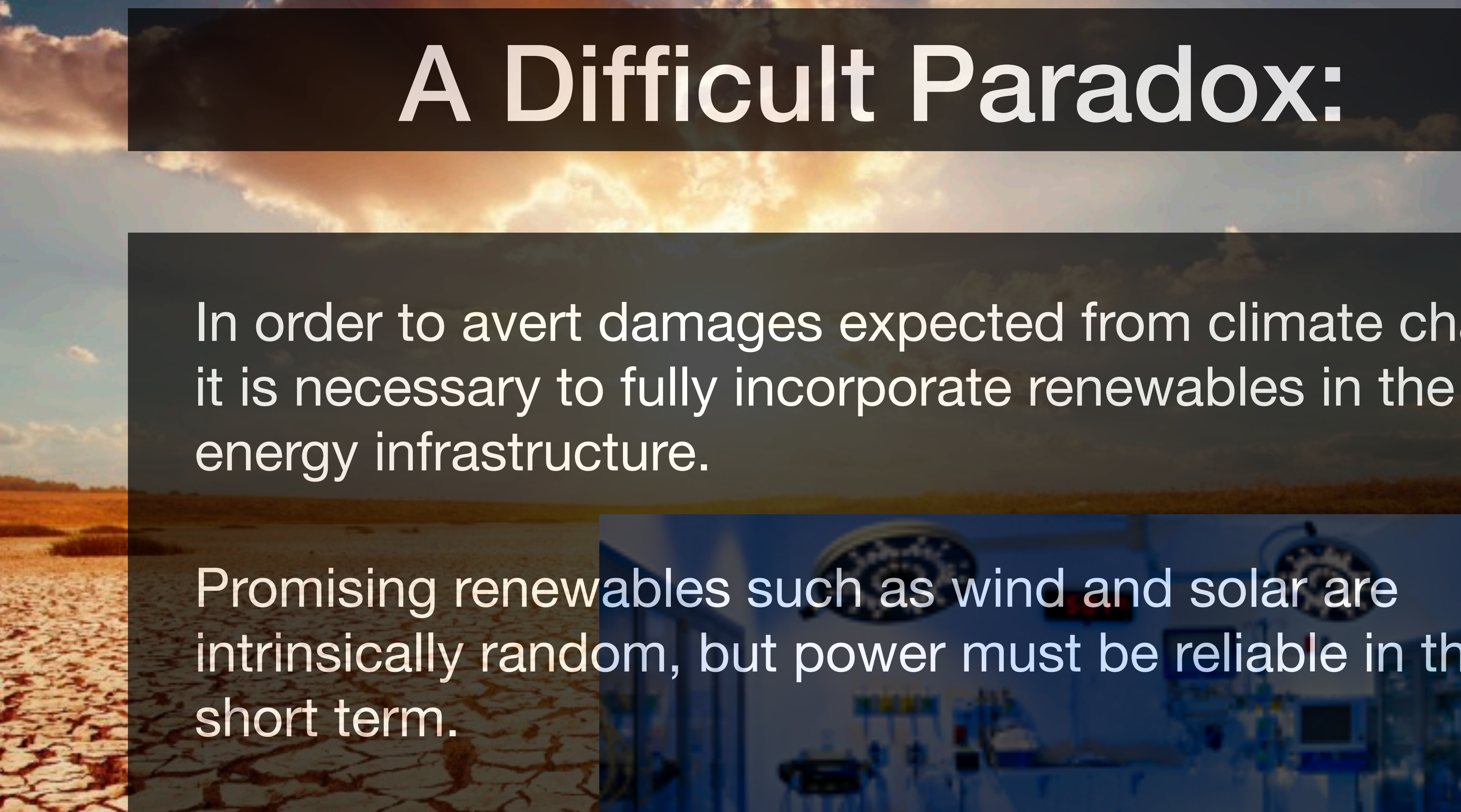
Grid Optimization
HEJC, Nov 8, 2018

Henry Wilkin (Physics)

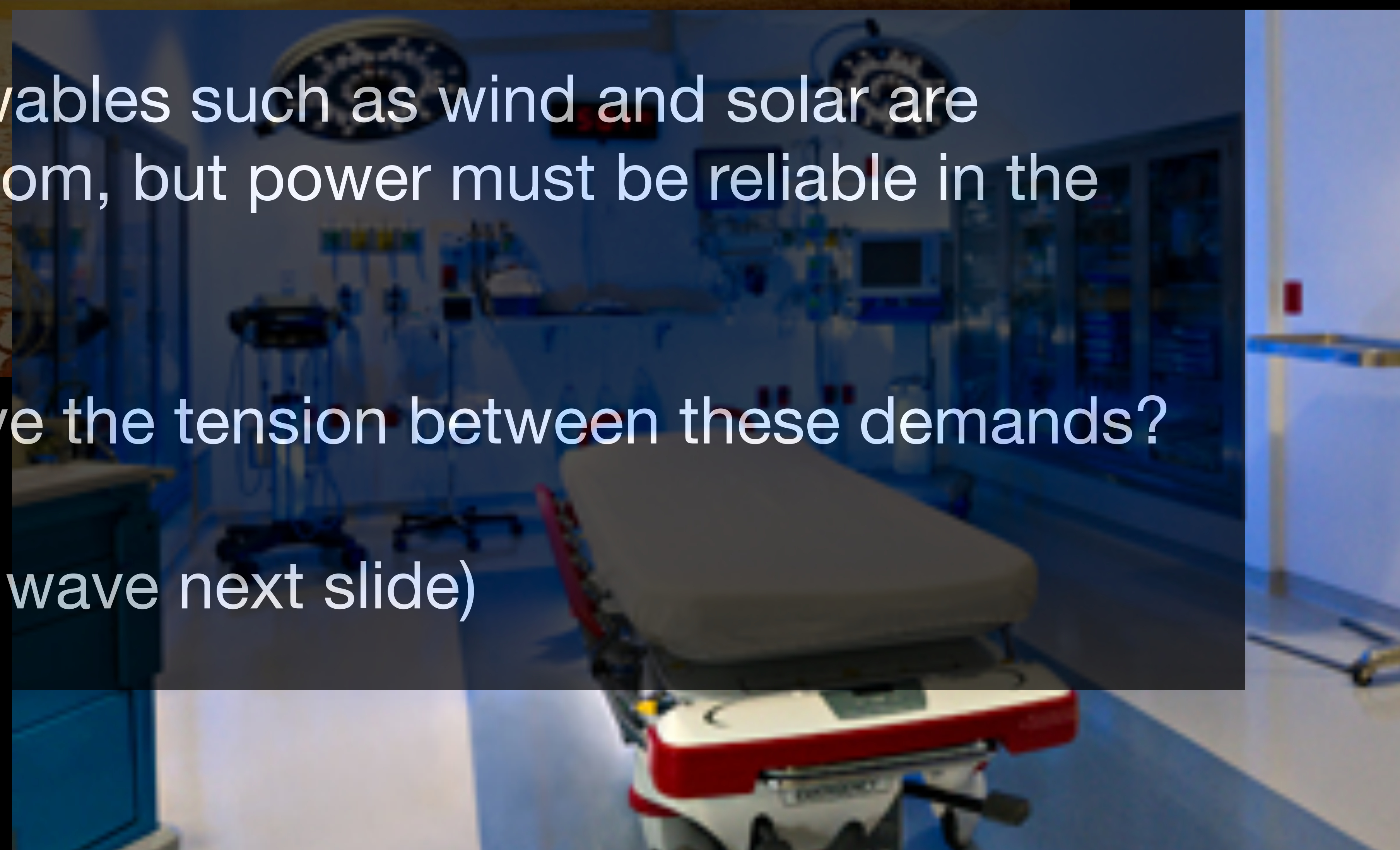


Source: Rugolo & Aziz, 2012

A Difficult Paradox:



In order to avert damages expected from climate change, it is necessary to fully incorporate renewables in the energy infrastructure.



Promising renewables such as wind and solar are intrinsically random, but power must be reliable in the short term.

How can we resolve the tension between these demands?

(CW Chicago heat wave next slide)

Case Study: Chicago Heat Wave, 1995

- “Stake out your turf at the nearest beach, pool, or air-conditioned store. Slow down… Think cool thoughts.” — Chicago Newspaper

- “This is the kind of weather we pray for” — air-conditioning salesperson

- “It often happens that a phenomenon is insignificant only because one fails to take it into account.”— Gaston Bachelard

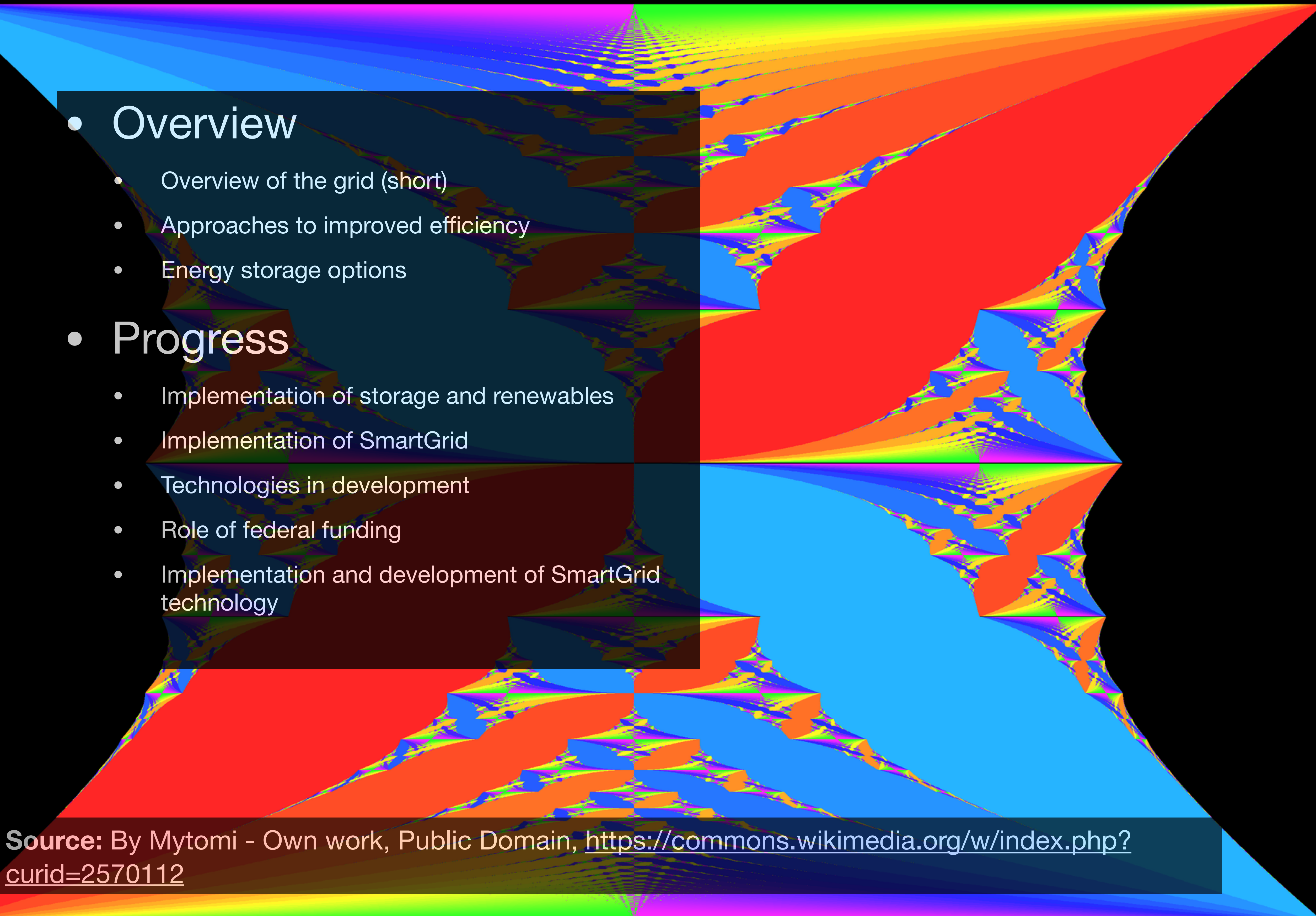
We’re always going to need more electricity, and we’re going to need to get more out of the electricity we have.

The question we wish to avoid having to ask:

“Who’s to blame?” —Chicago News Anchor

Source: Eric Klinenberg, *Heat Wave, a social autopsy of disaster in Chicago*

Overview



- Overview
  - Overview of the grid (short)
  - Approaches to improved efficiency
  - Energy storage options
- Progress
  - Implementation of storage and renewables
  - Implementation of SmartGrid
  - Technologies in development
  - Role of federal funding
  - Implementation and development of SmartGrid technology

Source: By Mytomi - Own work, Public Domain, https://commons.wikimedia.org/w/index.php?curid=2570112

What is the Grid?

“*a highway for delivering a product to millions of customers*”

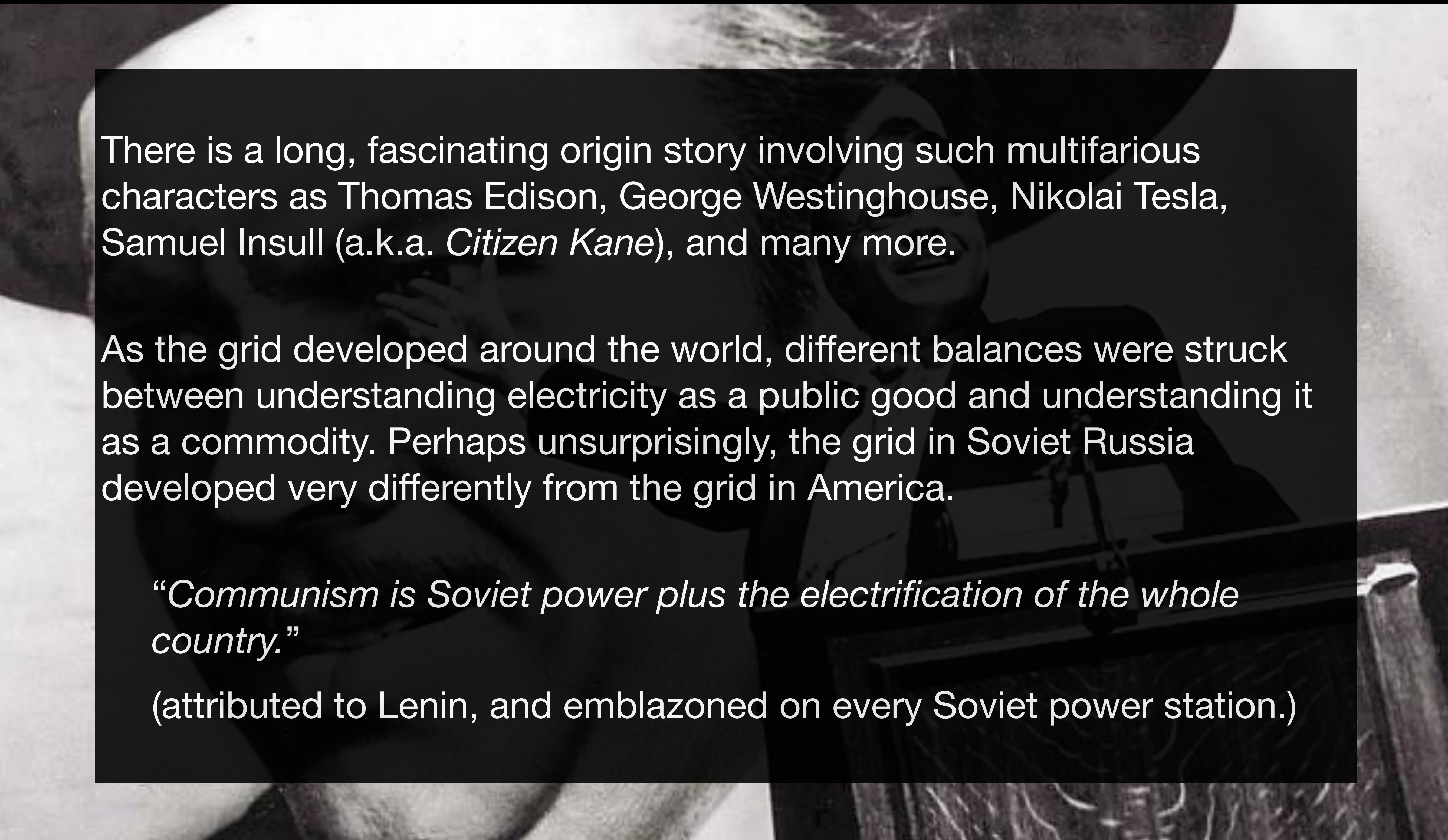
“a sort of NATO defense alliance of utilities pledged to help each other in time of need”

“a platform supporting a worldwide movement of information”

“a commodities exchange dispatching vast resources on a second’s notice.”

- Philip Schewe, *The Grid*

Whence the Grid?



There is a long, fascinating origin story involving such multifarious characters as Thomas Edison, George Westinghouse, Nikolai Tesla, Samuel Insull (a.k.a. *Citizen Kane*), and many more.

As the grid developed around the world, different balances were struck between understanding electricity as a public good and understanding it as a commodity. Perhaps unsurprisingly, the grid in Soviet Russia developed very differently from the grid in America.

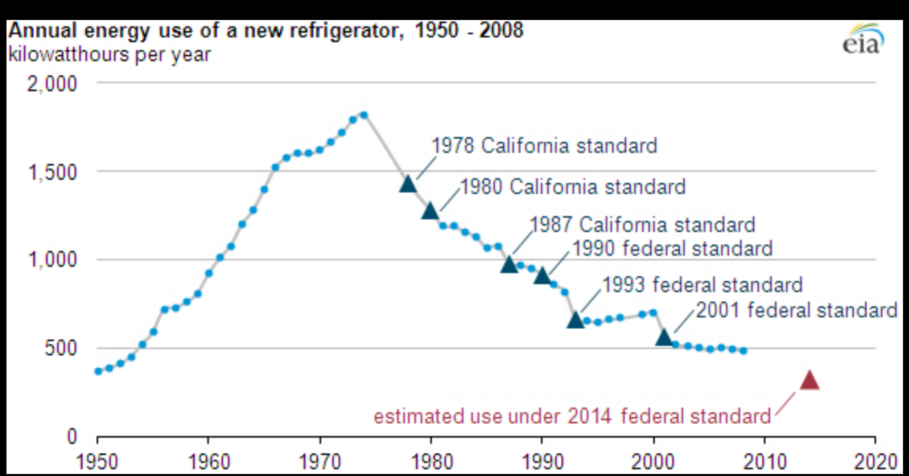
> “*Communism is Soviet power plus the electrification of the whole country.*”
>
> (attributed to Lenin, and emblazoned on every Soviet power station.)

Grid inefficiencies

Inefficiencies can (per usual) be broadly categorized as either wasted surplus (which is common) or unmet demand (rare.)

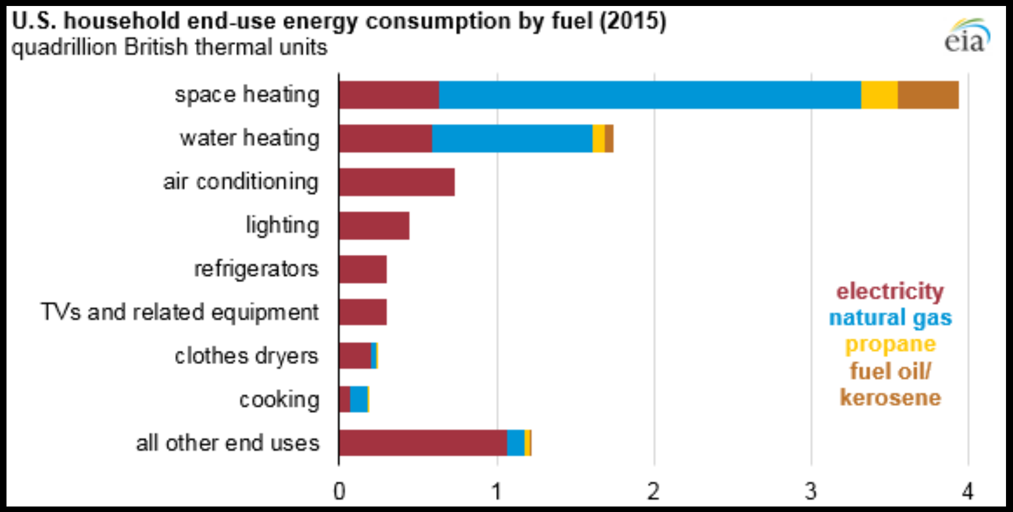
In addition, there is inefficiency from untapped, low-cost sources: for example, renewables.

And finally, *end use* efficiency can be improved as well



Source: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Building Technologies Office.

Source: Boston Globe, 2014



Source: https://www.eia.gov/todayinenergy/

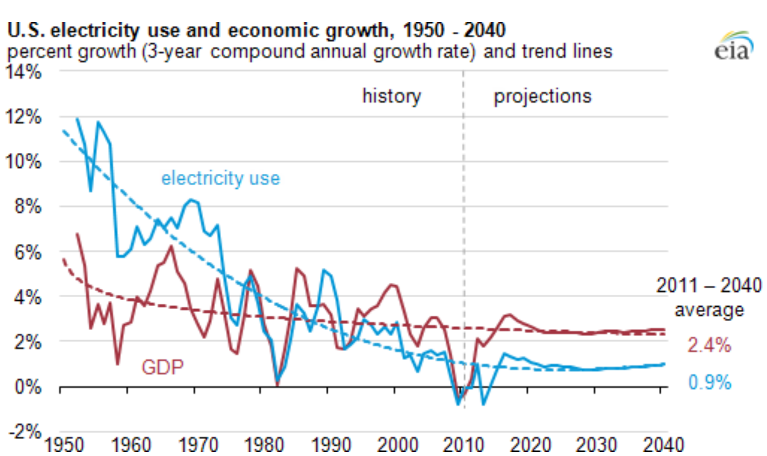
Grid inefficiencies:

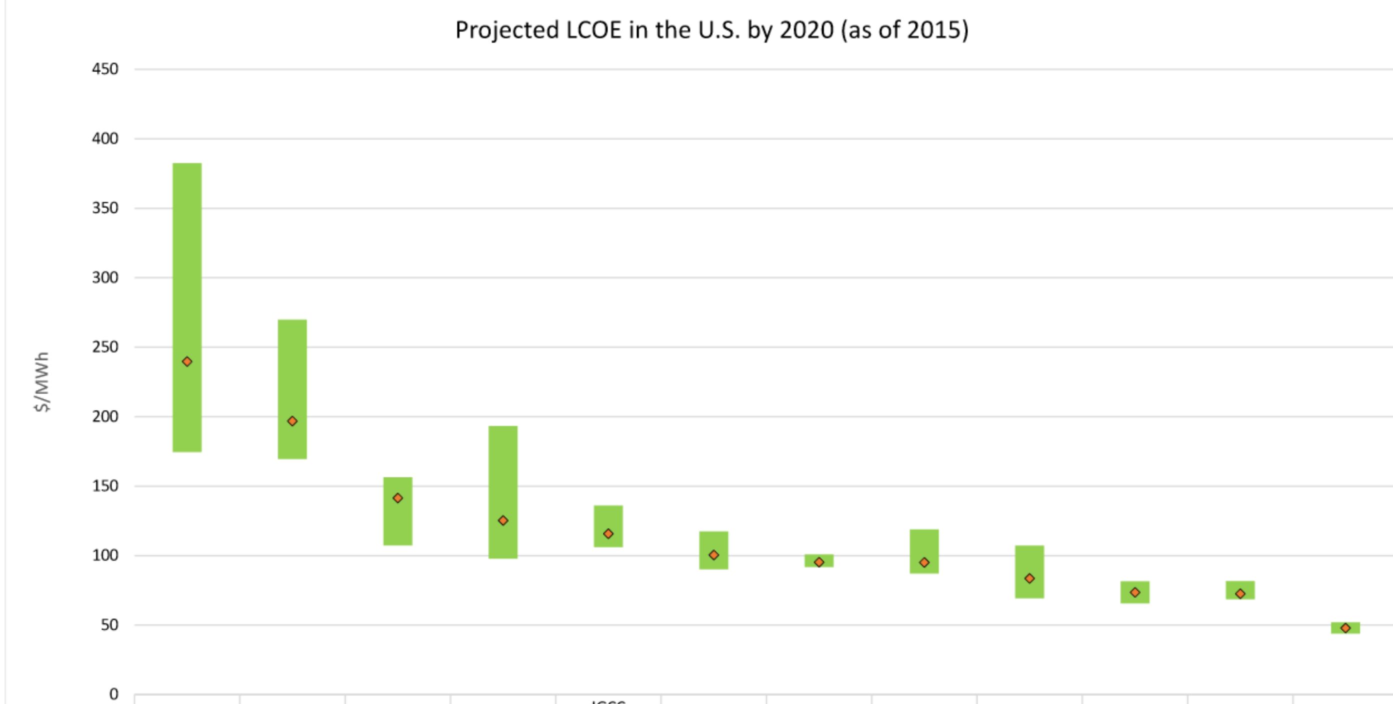
unmet demand

- Blackouts and power outages.
- Rare events when electricity is in high demand
- Overhead costs for electrification in sparsely populated areas

wasted surplus

- Available power is relatively flat, while demand fluctuates throughout the day
- To avoid outages, utilities sustain power in excess of the highest rate that could be drawn
- Since peak demand can be quite high, a large fraction of supplied power is dissipated





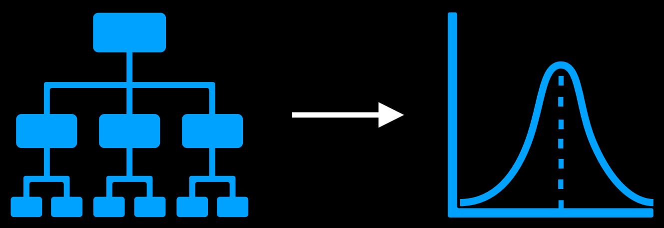
	Solar Thermal	Wind offshore	Natural Gas: Conventional Combustion Turbine	Solar PV	IGCC (Integrated Coal-Gasification Combined Cycle)	Biomass	Advanced Nuclear	Conventional Coal	Hydro	Wind onshore	Natural Gas: Advanced Combined Cycle	Geothermal
Minimum	174	170	107	98	106	90	92	87	69	66	69	44
◆ Average	240	197	142	125	116	101	95	95	84	74	73	48
Maximum	383	270	156	193	136	117	101	119	107	82	82	52

Putting the central limit theorem to use

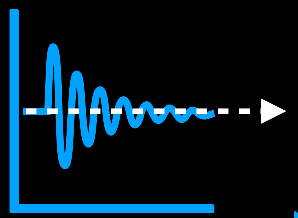
Fluctuating demand can be reduced by effectively averaging over time and space, either with improved infrastructure or by rationally adjusting costs.

That is, through

- Transmitting power to more people at once (e.g. Beijing's global grid project.)



- Storing excess energy until it is needed

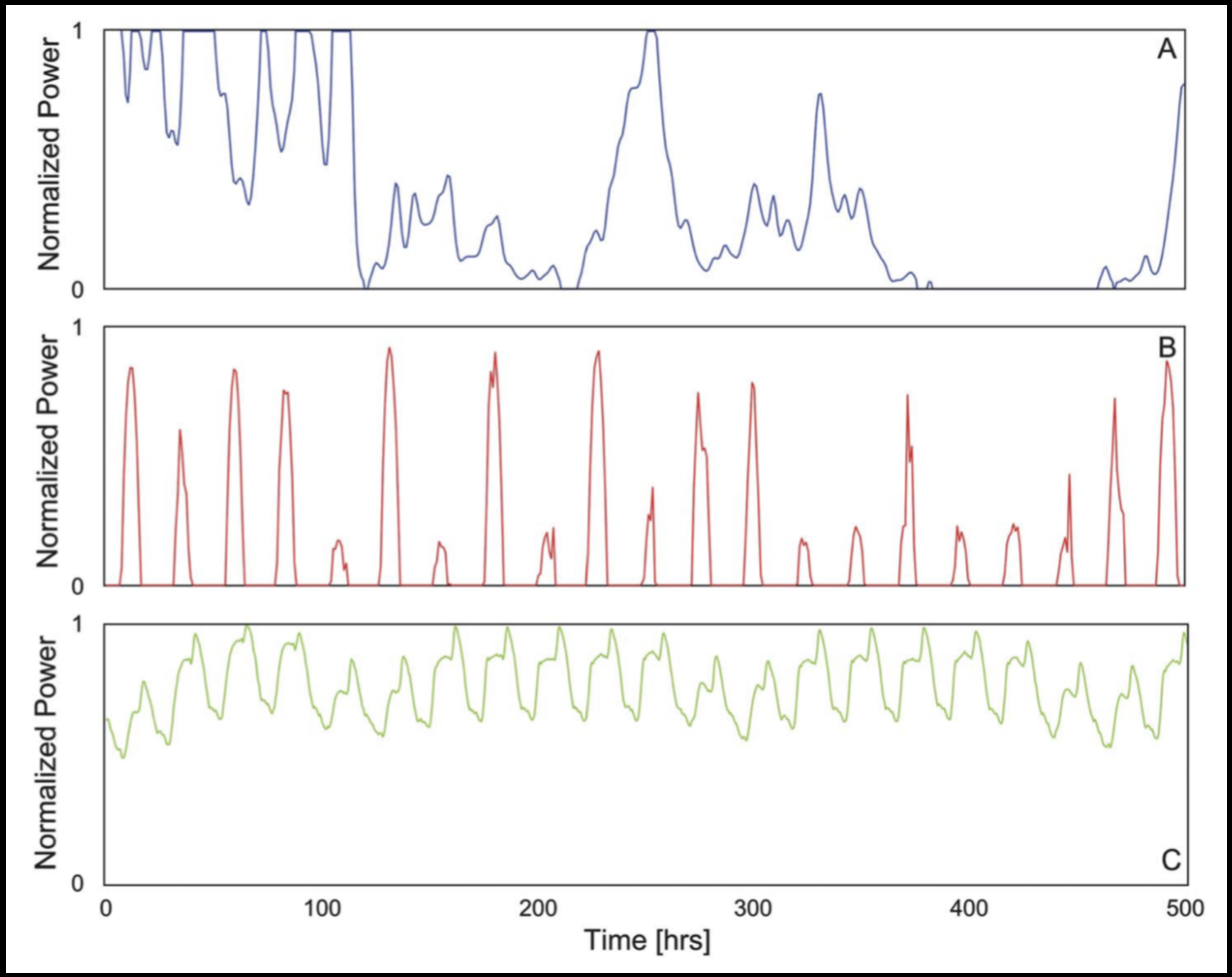


- Deferring consumption

Fundamental Constrain: variable and rigid production

- Most large power plants need to operate at fixed voltage for large stretches of time, while demand fluctuates.
- Power from wind and solar fluctuates naturally.

How can these fluctuations best be accommodated?



Rugolo, J., and Aziz, M. J. Energy Environ. Sci., 2012, 5, 7151

Fundamental constraint: Energy Storage

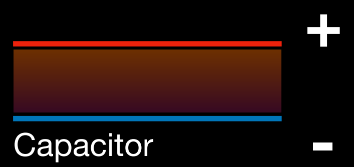
Each storage technology has a characteristic response time, and can be combined in ways that recuperate the most surplus energy.

In rough order of sensitivity: (non-exhaustive)

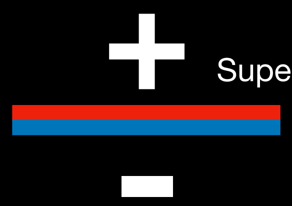
- Electrical* (e.g. supercapacitors)
- mechanical (e.g. flywheels)
- gravitational (e.g. pumped hydrostorage)
- thermal (e.g. molten salt)
- chemical*, (e.g. lithium ion batteries, thermochemical)

Each storage mode can be tuned to some extent as well.

Basic ingredients for tuning electricity output

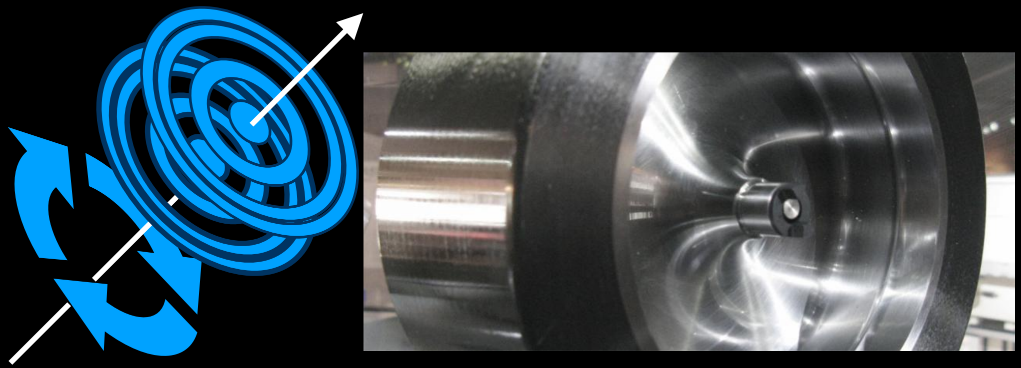


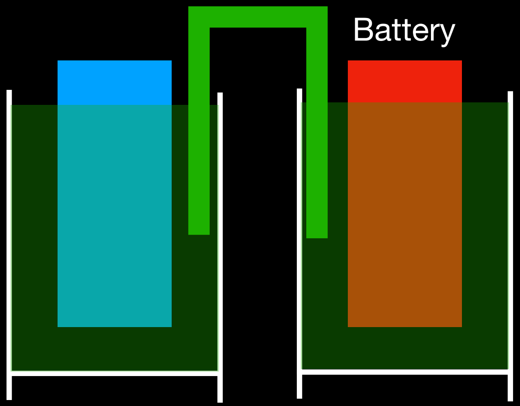
Capacitor



Supercapacitor

Thermal


Flywheel


Battery

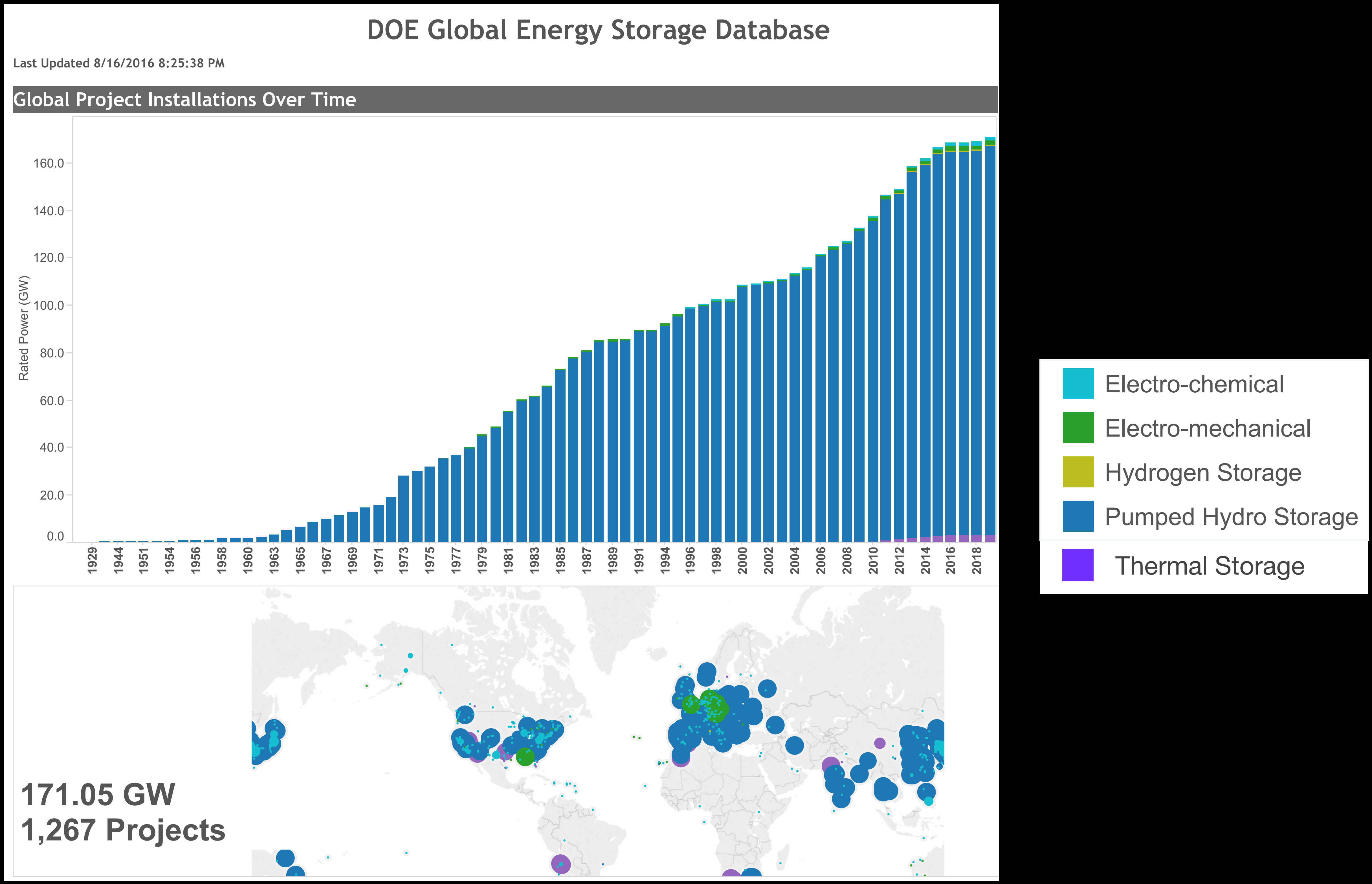
DOE Global Energy Storage Database

Great way to keep track of new developments in electric storage.

http://www.energystorageexchange.org

(A lithium ion power balancing storage facility)

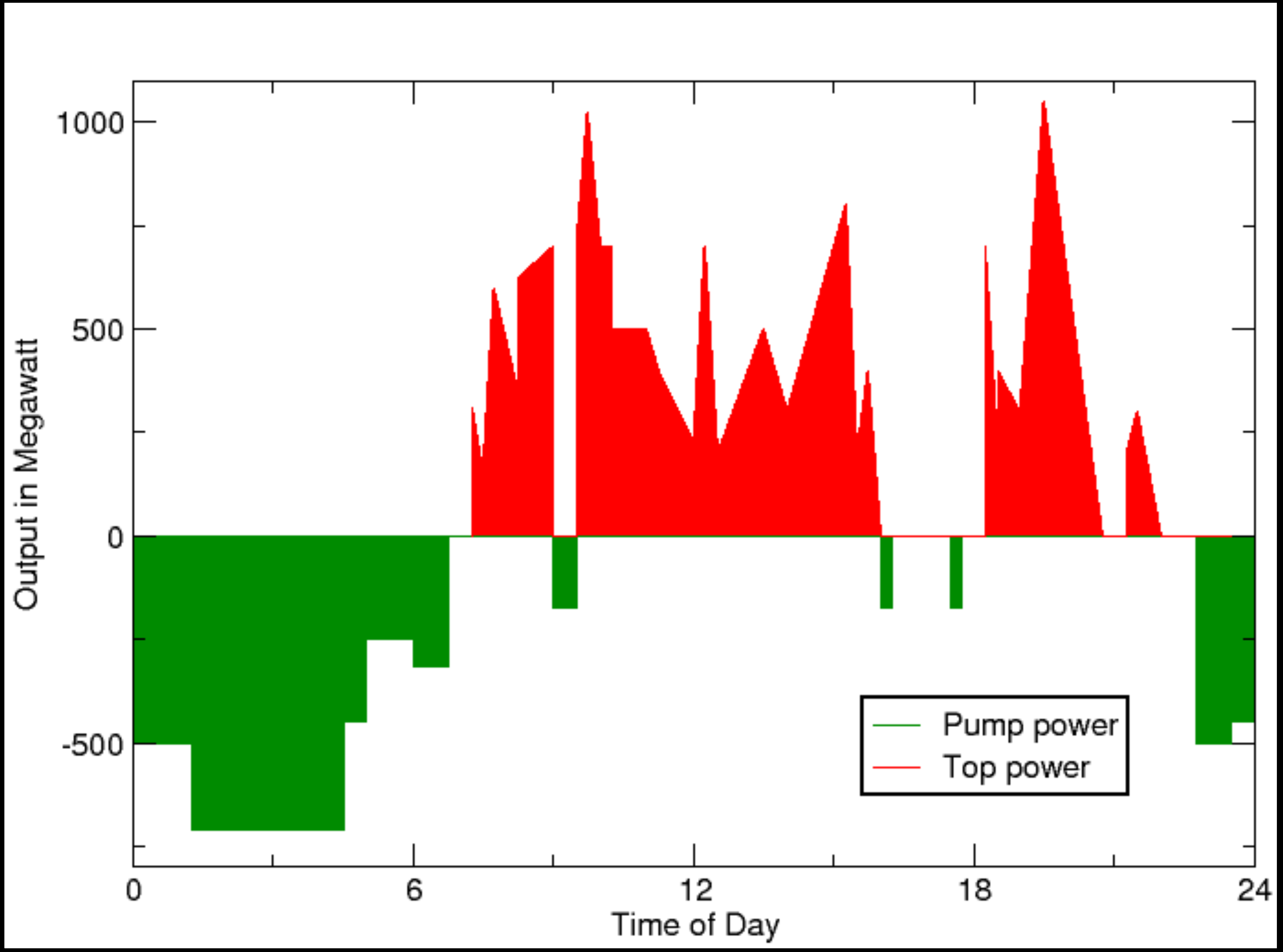
Implementation



Pumped hydroelectric

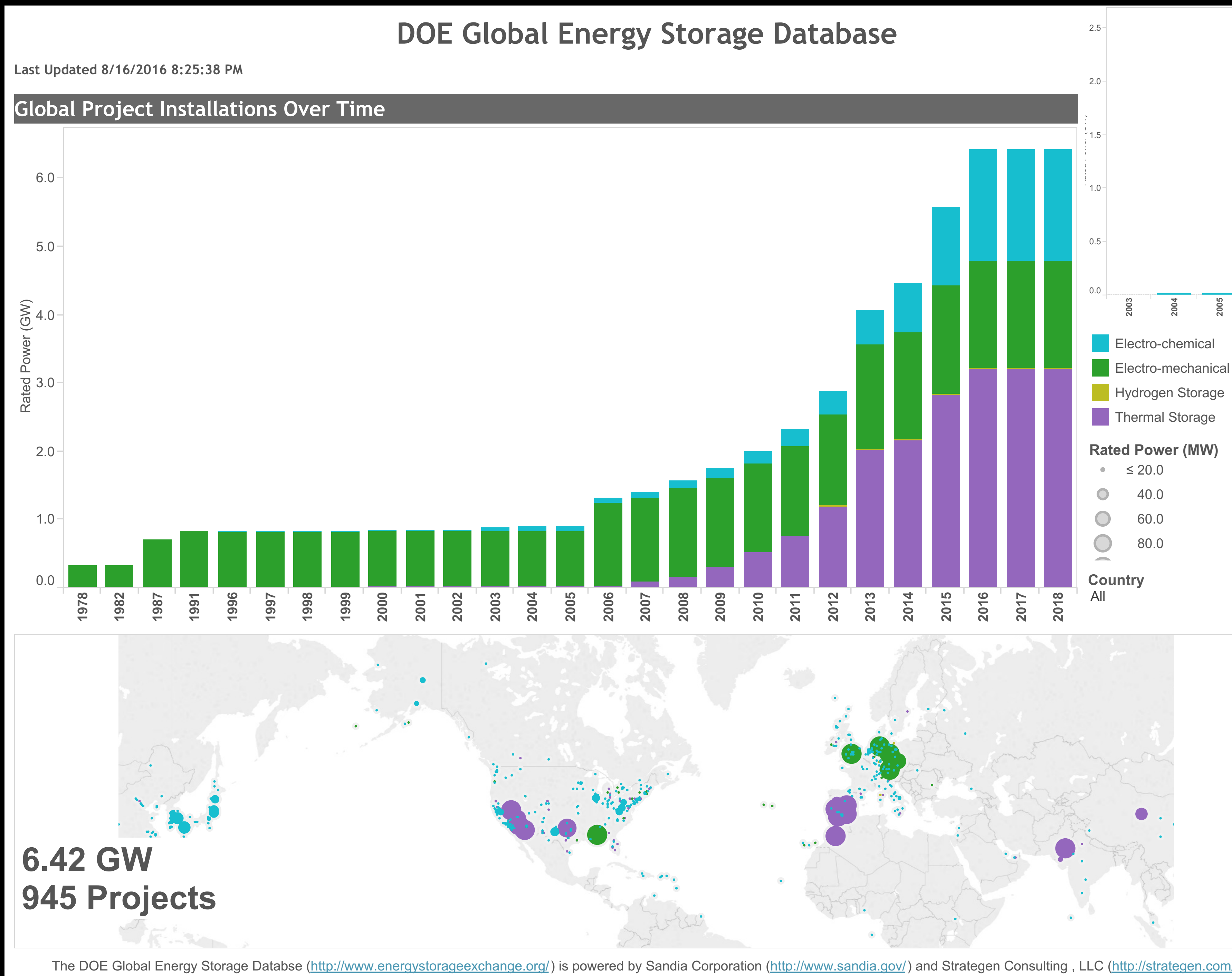
- Forms the vast majority of present storage
- Limited by geography, environmental capacity, topography.
- Efficient , but doesn't scale especially well

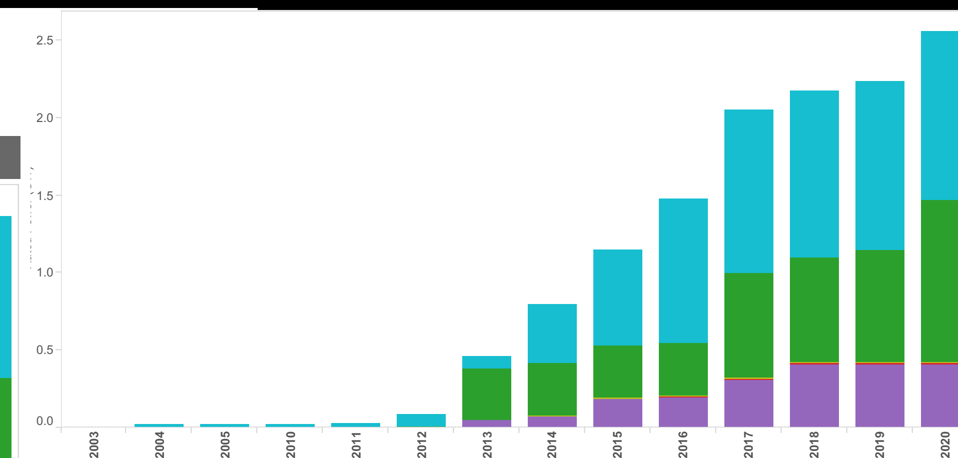
Example power output profile (from a plant in Germany)



Source: Own [unknown user] diagram based on a publication of the Rheinisch-Westfälisches Elektrizitätswerk RWE Germany

Non-hydro storage





(Announced, contracted, under construction)

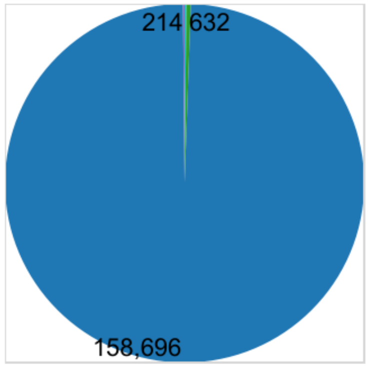
On the rise are thermal, electro-chemical,

Invisible but definitely there, hydrogen storage

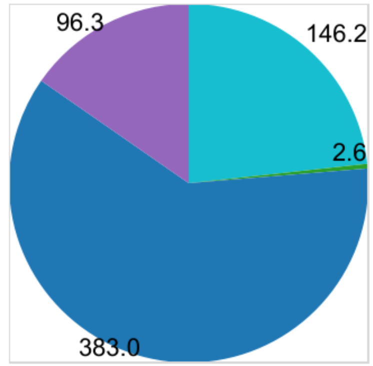
DOE Global Energy Storage Database

Last Updated 8/16/2016 8:25:38 PM

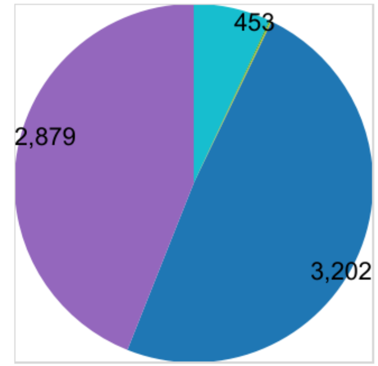
Electric Energy Timeshift (MW)*



Electric Bill Management (MW)*



Renewables Capacity Firming (MW)*

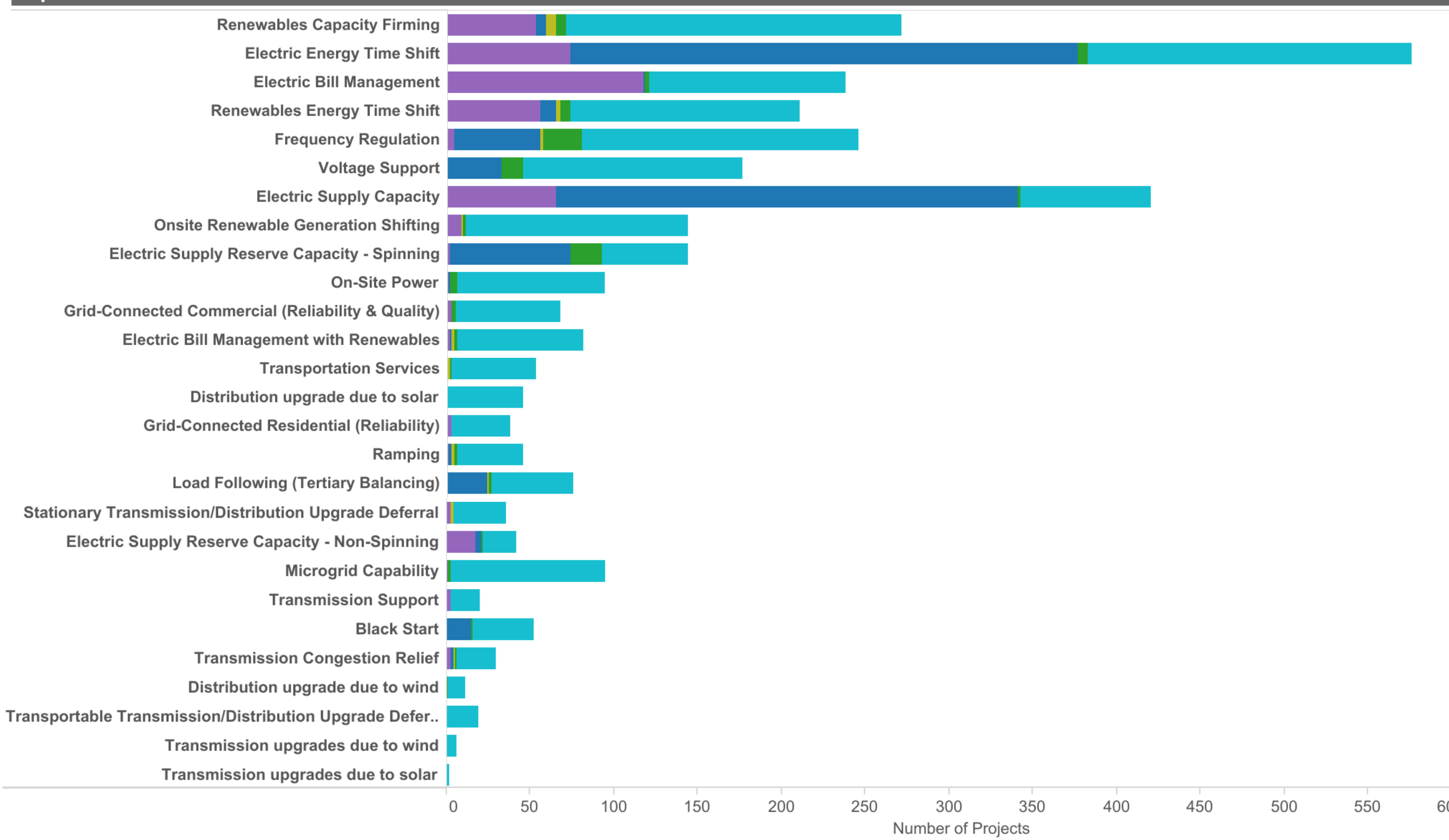


Technology
All

Status
Operational

- Electro-chemical
- Electro-mechanical
- Pumped Hydro Storage
- Thermal Storage

Top Use Cases



*Projects can have multiple use cases

The DOE Global Energy Storage Databse (http://www.energystorageexchange.org/) is powered by Sandia Corporation (http://www.sandia.gov/) and Strategen Consulting , LLC (http://strategen.com/)

Role in Renewables Penetration

A 2015 paper by Mark Jacobson and others describes how, in principle, our current energy needs can be met with 100% renewable power generation (by 2050)

Claim storage problem can be resolved using just

- Excess heat storage (soil & water)
- Phase-change material
- Pumped hydrostorage
- Hydrogen (fuel cell)

With basic smart-grid features (e.g. response for excess demand.)

Look up *100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for the 50 United States.*

(caveat: geothermal is used as well)

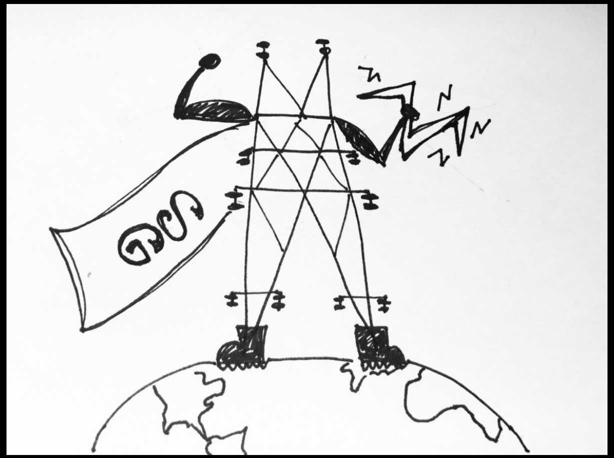
Policy

Smart vs. Super

In the short term, there are essentially two broad approaches to incorporating these elements to improve grid efficiency and reliability have been proposed.

- **Smartgrid:** use energy storage and data to allow optimized power consumption at each scale and to synchronize a more distributed network of providers. Automatically set prices with enhanced precision, and give users the tools to be more selective with their power consumption.

- **Supergrid:** merging existing grids into a larger grid, (hopefully with lower relative fluctuations.) Using tech that improves with scale (e.g. low voltage high current superconducting wires, high voltage DC power transfer.) Relies on free market forces to drive innovation at smaller scales. (Averaging over space)

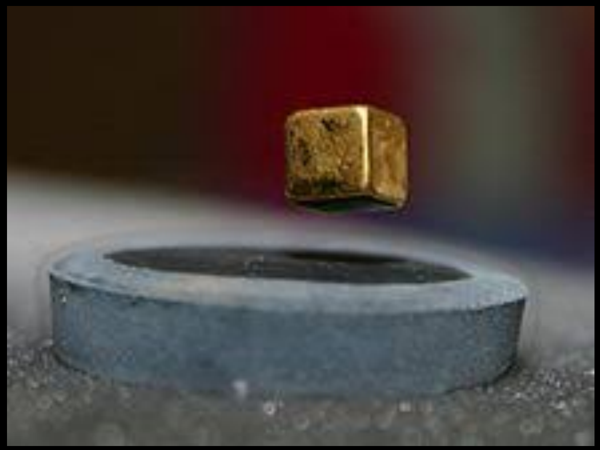


Source: Google Images, 'SuperGrid'

Source: Harry Jones, 2008: *Superconductors in the transmission*

Why not both?

Sure! But it isn't *obvious* a priori that development of one technology translates directly to the other.



Also, the end result of the grid might depend on the particular approach taken.

Smart Grid Attempt: Massachusetts

How do proposed smart-grid plans fail to catch on?

- Proposal by Western Massachusetts Electric Co. rejected because it “would have unfairly targeted low-income customers and circumvented [MA] laws meant to help struggling consumers keep the lights on.”
- Clumsy wording: the deal was to pay in advance for vaguely specified “‘basic' necessities”, and then a premium for anything extra.
- In seeming violation of state consumer protection laws
- “The proposal from Western Mass. Electric was imaginative in some ways, but I think it was potentially harmful, particularly for households with low incomes”
- “[Smart grid technology is] a tool. From an environmental point of view, we’re hopeful that if used right, it can do a lot of good.” — Seth Kaplan (Conservation Law Foundation)

Important to communicate thoroughly in advance of proposals

Many energy sources and storage modes depend strongly on geography. How can the benefits travel further? Also, how can transmission losses be reduced?

- Replace AC transfer with high voltage DC or even high capacity superconductive wire
- *Self-healing* grid infrastructure

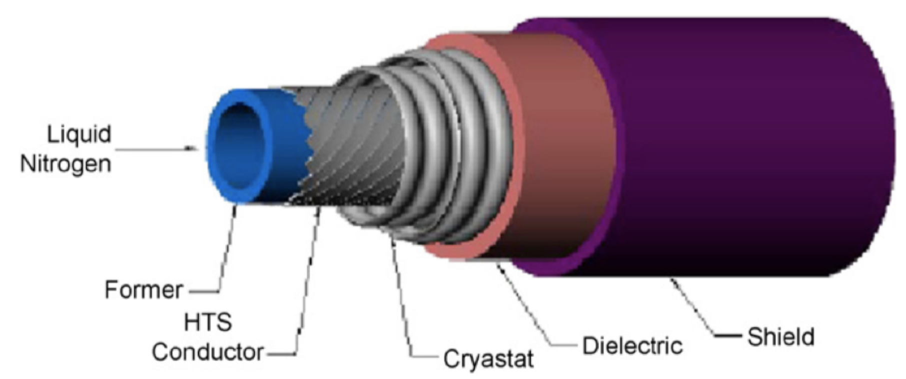


Fig. 1. Warm dielectric (courtesy of Ultera).

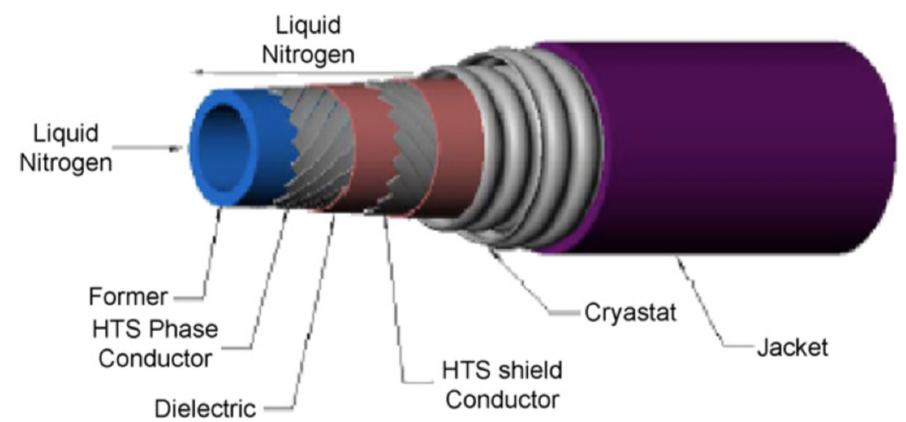


Fig. 2. Cold dielectric (courtesy of Ultera).

To be continued…

References

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- Supergrid or Smartgrid: competing strategies for large-scale integration of intermittent renewables? (Blarke & Jenkins 2013)
- Review of energy storage technologies
- The state of technological innovation related to the electric grid (Committee on Energy and Natural Resources U.S. Senate, 2015)
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- Rugolo J., Aziz M., 2012. *Electricity storage for intermittent renewable sources.*