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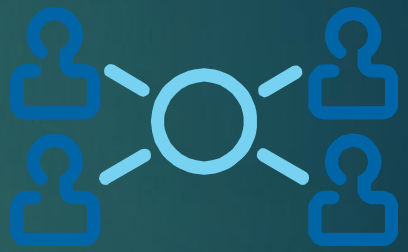

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Thermal Energy Storage Technology to Enable Microgrids with Renewable Energy Generation

Douglas Reindl, Ph.D., P.E.
Professor, University of Wisconsin-Madison
dreindl@wisc.edu

In this presentation, I am planning to cover

- Electricity supply – Overview of key issues arising in our electric utility systems today including growth of renewable generation
- Microgrids – What are they and potential role in the future electricity supply
- Thermal storage – How and why it is a strategic technology that more effectively utilizes generation capacity while enable greater deployment of renewable energy

What current event(s) are impacting our energy systems?

(with a focus on electricity)

Microsoft deal propels Three Mile Island restart, with key permits still needed

By **Reuters**

September 21, 2024 11:58 AM CDT · Updated 6 months ago

PRESS RELEASE
February 24, 2025

Apple will spend more than $500 billion in the U.S. over the next four years

Teams and facilities to expand in Michigan, Texas, California, Arizona, Nevada, Iowa, Oregon, North Carolina, and Washington

Plans include a new factory in Texas, doubling the U.S. ufacturing academy, silicon engineering

New York passes law banning fossil fuel equipment in most new buildings

d Toward

Five-year US load growth forecast surges 456%, to 128 GW: Grid Strategies

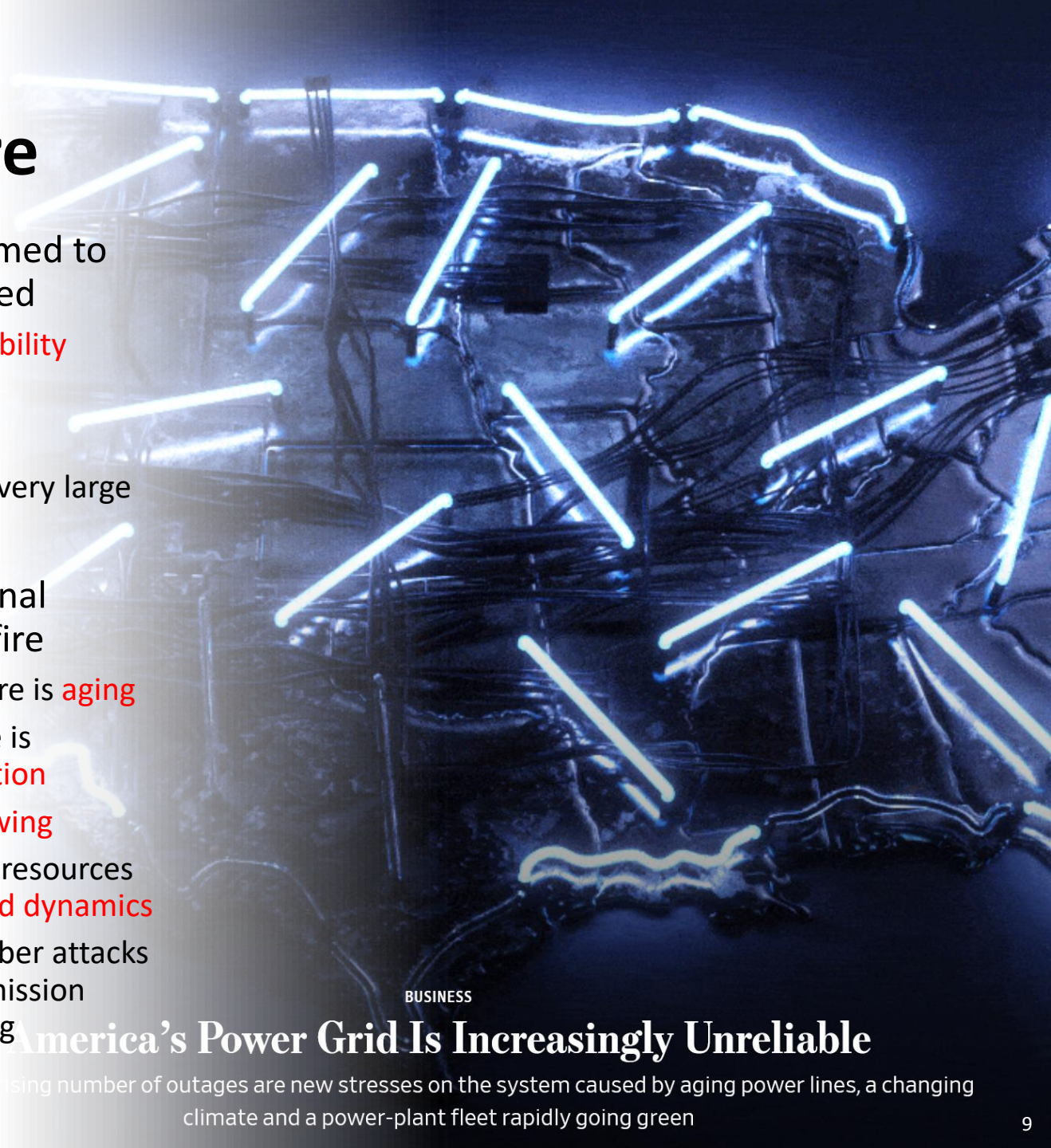
U.S. electricity demand is forecast to increase 15.8% by 2029, according to a new report from Grid Strategies. Six regions of the country are driving the growth.

Published Dec. 6, 2024

Robert Walton
Senior Reporter

Electricity infrastructure

- We have grown accustomed to electricity that is delivered
  - With extremely high reliability
  - With resiliency
  - At a low cost
  - In capacity from small to very large
  - …
- Yet, many of these nominal expectations are under fire
  - Transmission infrastructure is aging
  - Generation infrastructure is undergoing a transformation
  - Customer demand is growing
  - Increased inverter-based resources is creating challenging grid dynamics
  - Risk of physical and/or cyber attacks on generation and transmission infrastructure is increasing
  - …



A few thoughts

- "Everything *is* tied to having electricity, and yet we're not focusing on the reliability of the *grid*. That's absurd, and that's frightening," he said. "There's such an emotional drive to get where we want to get on climate change, which I understand, but we can't throw out the idea of having a reliable *grid*."

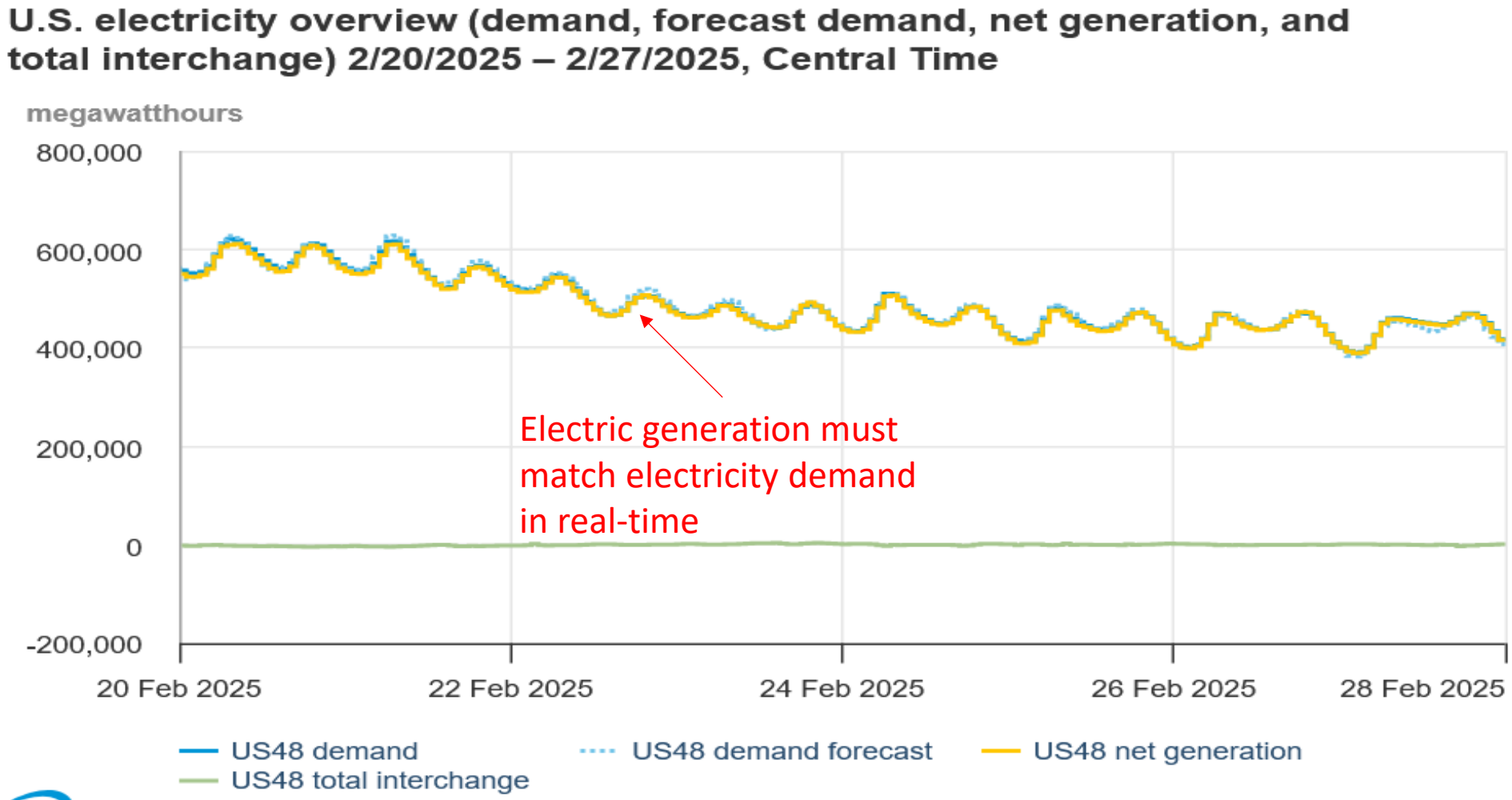
  Curt Morgan, CEO of Vistra Corp.

- "One of the biggest challenges facing grid operators and utility companies is the need for better technology that can **store large amounts of electricity and discharge it over days**, to account for longer weather events that affect wind and solar output. Most large-scale batteries currently use lithium-ion technology, and can discharge for about four hours at most."

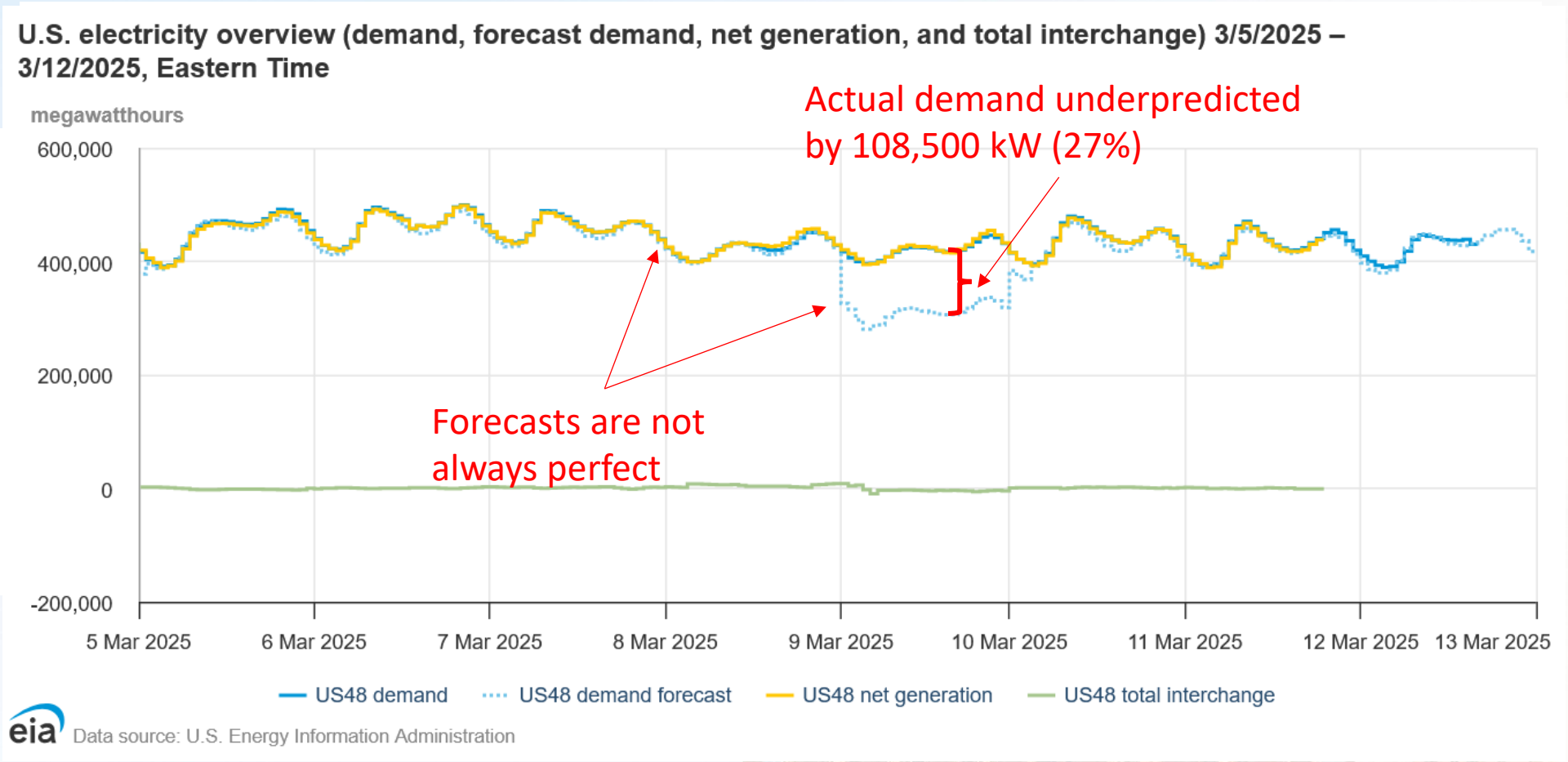
  Katherine Blunt

Source: "America's Power Grid Is Increasingly Unreliable; Behind a rising number of outages are new stresses on the system caused by aging power lines, a changing climate and a power-plant fleet rapidly going green", Katherine Blunt, *Wall Street Journal*, Feb 18, 2022.

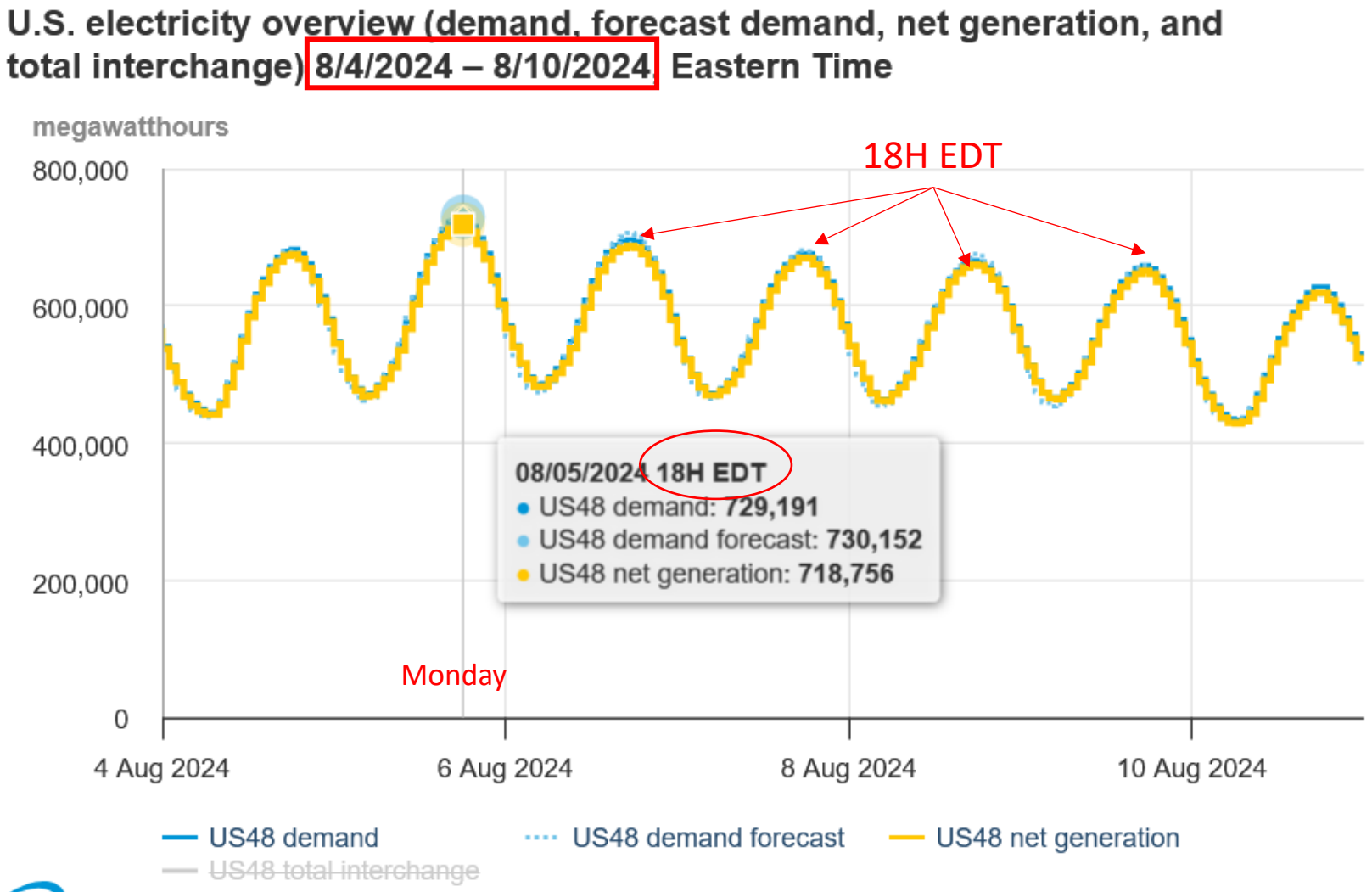
Electric utilities and grid operators must continuously match generation with customer demand



Electric utilities and grid operators must continuously match generation with customer demand



Summer peak demands are driven by A/C
(hold this thought)



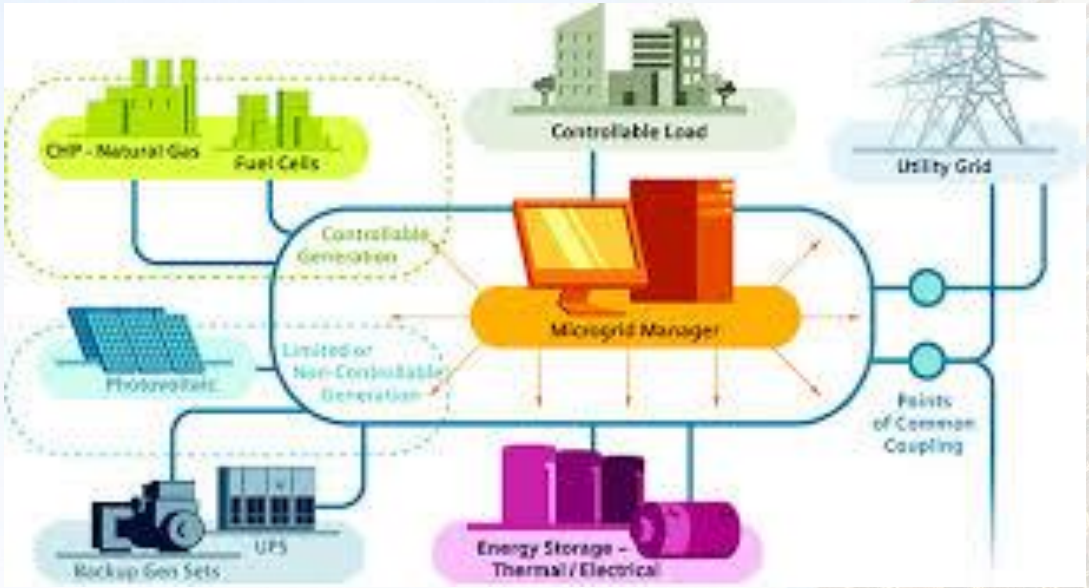
eia Data source: U.S. Energy Information Administration

What is a microgrid?

"A group of interconnected loads and distributed energy resources (DERs) within clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid.

A microgrid can connect and disconnect from the grid to enable it to operate in both connected or island-mode."

U.S. DOE Microgrid Exchange Group



Source: "Microgrids: An Old Concept Could Be New Again", *Power* 8/1/17

Distributed energy resources includes distributed generation

- Distributed generation is “the integrated or stand-alone use of small modular resources by utilities, utility customers, and third parties in applications that benefit the electric system, specific customers, or both” [EPRI]
- DG technologies include: PV, wind turbines, fuel cells, microturbines, SMRs, IC engine gen sets, among others

DG Examples

Wayne Industrial Sustainability Park in Ontario, NY

250 kW & 850 kW wind turbines

Beacon Falls Energy Park (CT)

6

a

n

8

ve

Northfield Area Solar Garden (Northfield MN)

6.63 MW of PV

Microgrid examples

- University campuses
- Military bases
- Remote networks such as island communities
- Industrial and manufacturing campuses
- Large residential and light commercial developments

Potential benefits of microgrids

- Closer proximity between power being generated and consumed
  - Lower transmission and distribution line losses
- Smaller generation affords increased ability to ramp up or down and to start/stop
- Potential to better integrate combined heat and power
- More manageable scale for dynamic grid control using approaches like DER
- Increased grid resiliency
- Energy storage is a key component of reliability

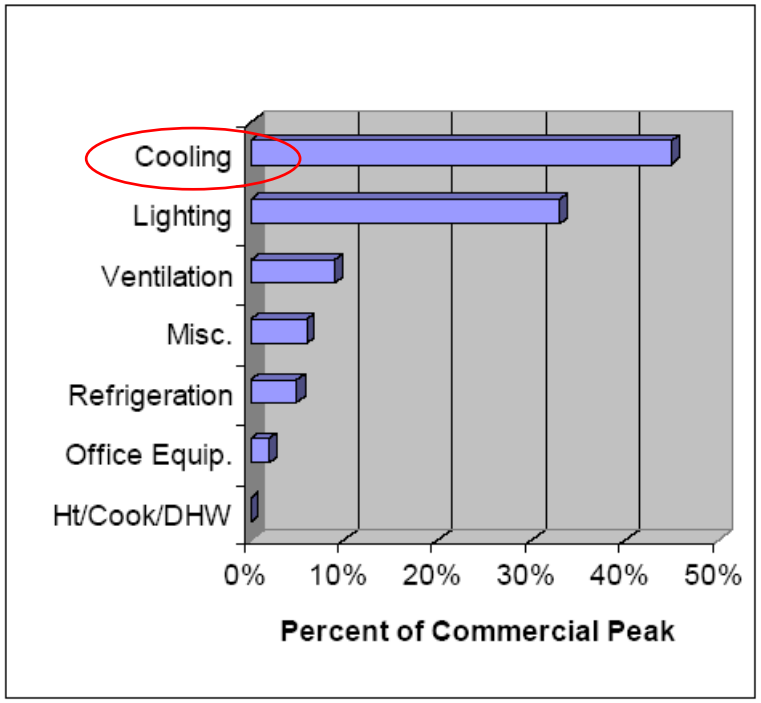
Energy storage provides flexibility

- Decouples demand from supply
  - Allows “production” of storage when
    - Resources are available
    - Costs are low
  - Bridges demand-production mismatches
- Affords potential downsizing for some equipment
- Enhances reliability/redundancy
- Can be located on the supply side or demand side of the meter
- Potentially increases end-use operating efficiency

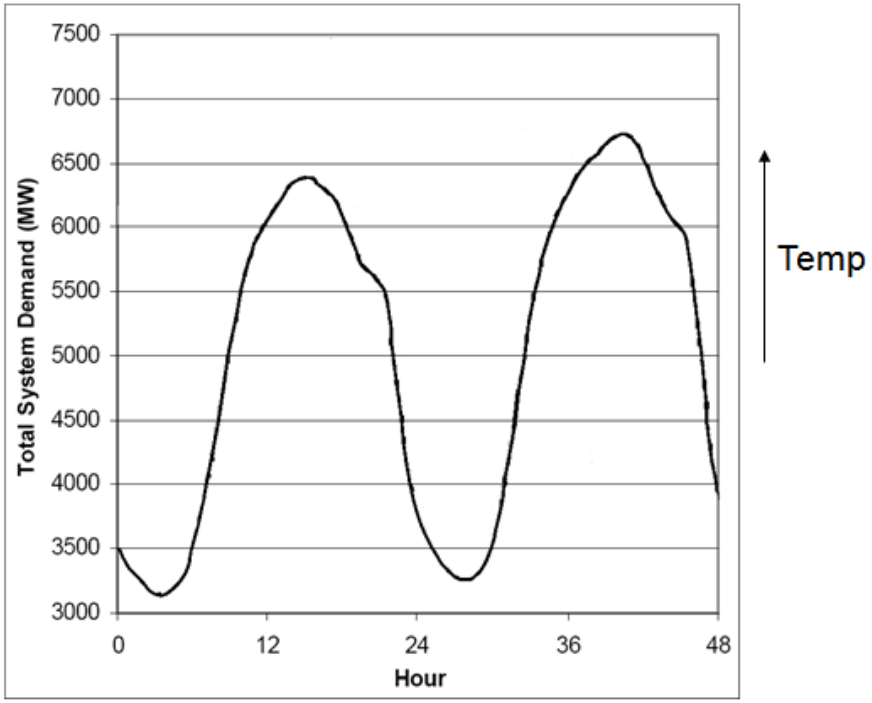
What energy storage technologies come to mind?

Remember we saw peak demand driven by A/C

Commercial Building Demand



Summer Peak and Temperature

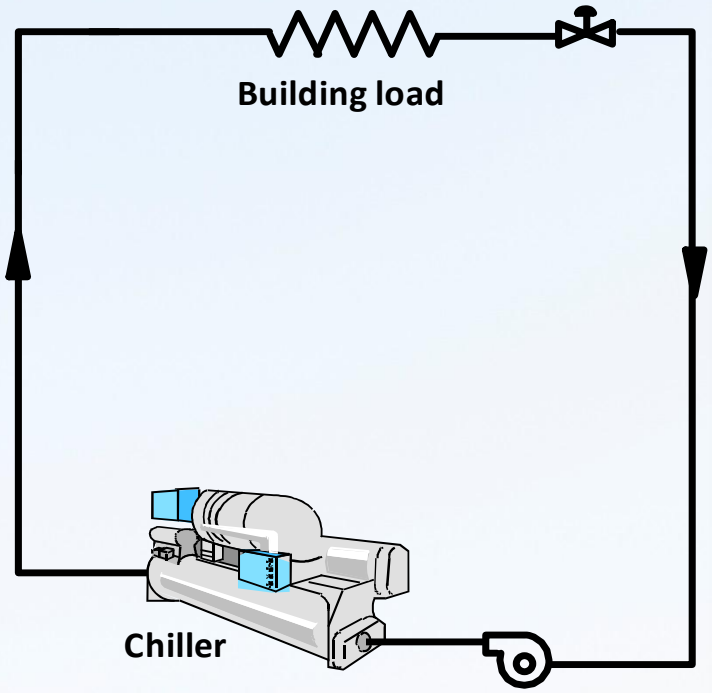


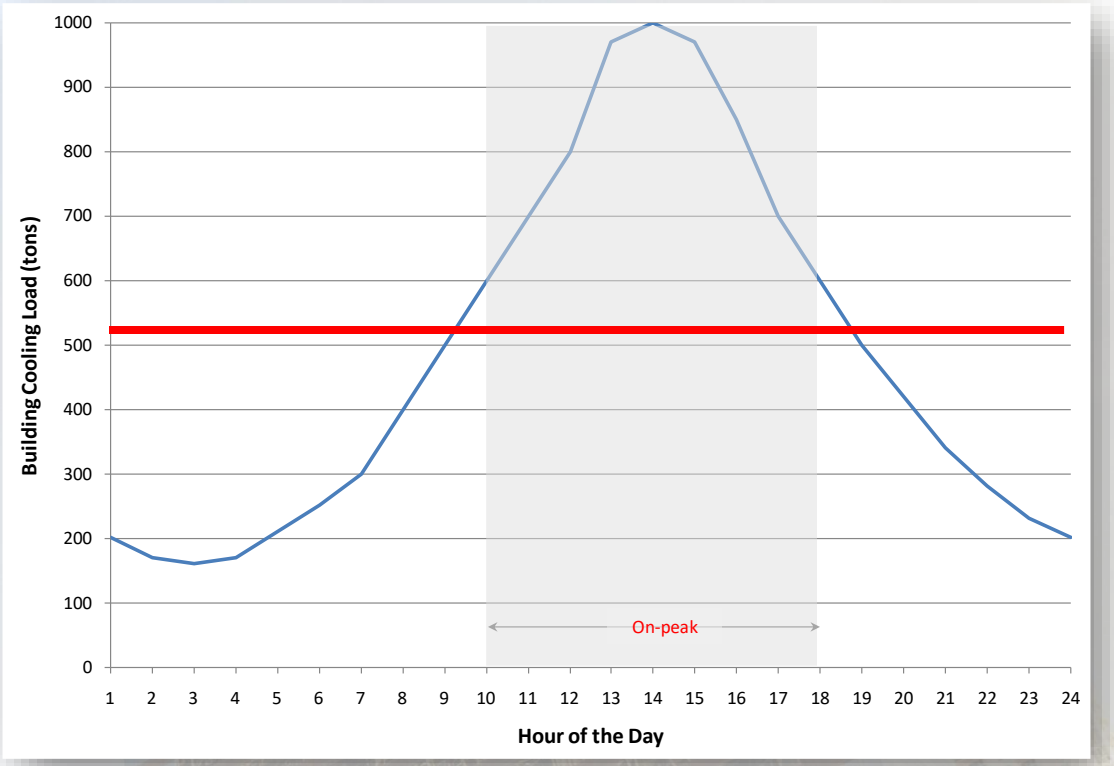
Most electric utilities experience their peak demand during the summer, driven by midday and early evening air-conditioning demand*

*Source NREL *Technical Report* NREL/TP-640-41410 May 2007

Typical building chilling system

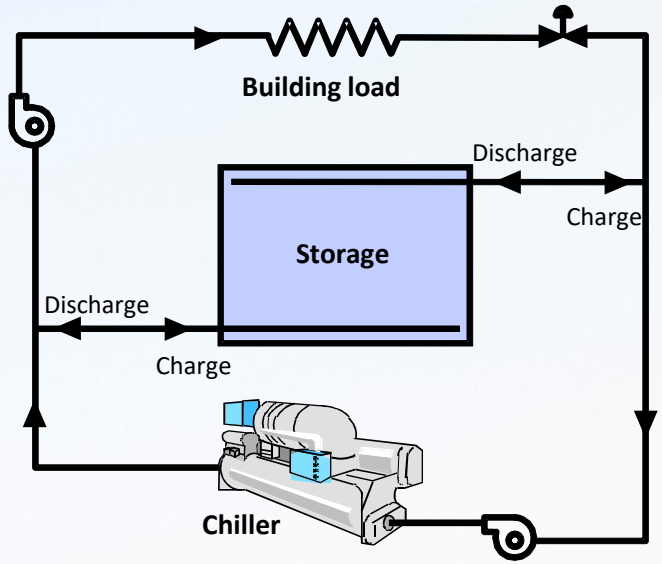
- Refrigeration plant connected directly to building loads
  - Must operate whenever cooling loads exist
  - Refrigeration capacity modulates in response to load

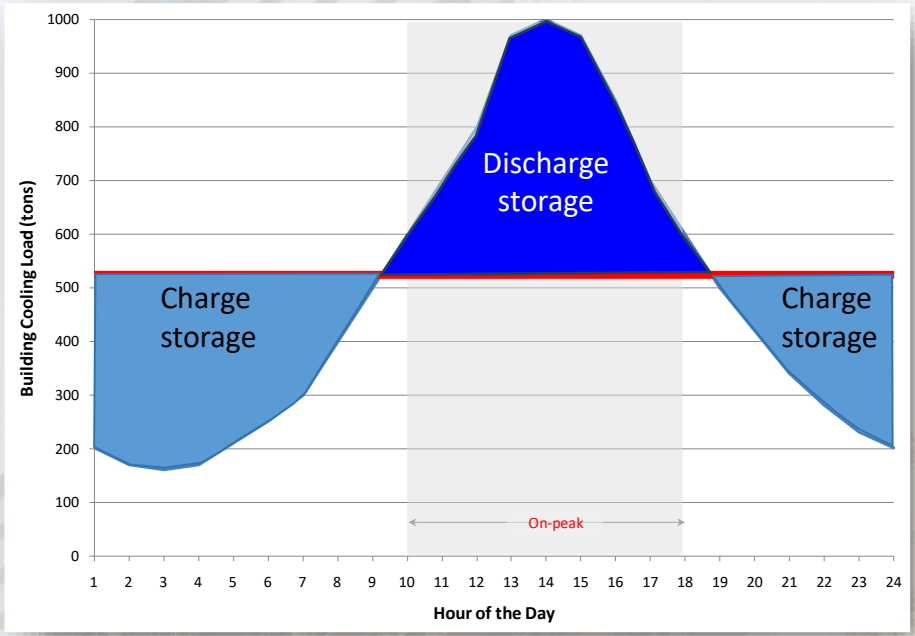




Cool thermal storage concepts (traditional)

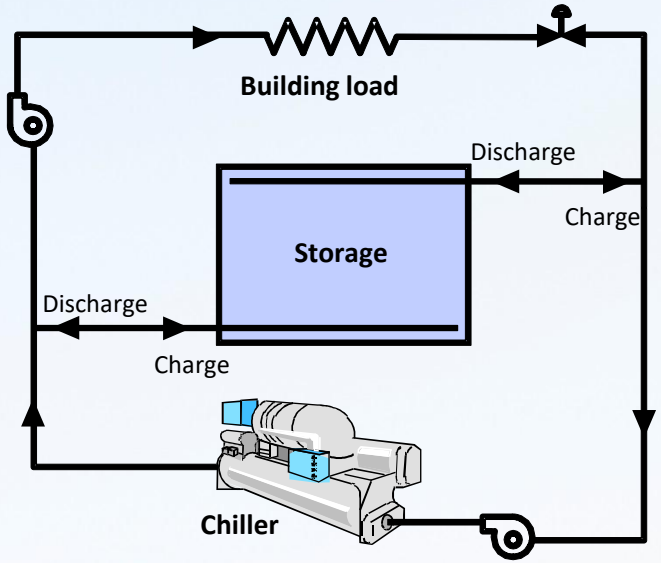
- Decouples energy-intensive cooling generation from building load demands
- Matches total cooling load to chilling capacity over time
- Enables downsizing chillers (meets average load instead of peak)
- Shifts consumption of electricity from (1) periods when it is available to when it is not or (2) high cost to low cost periods

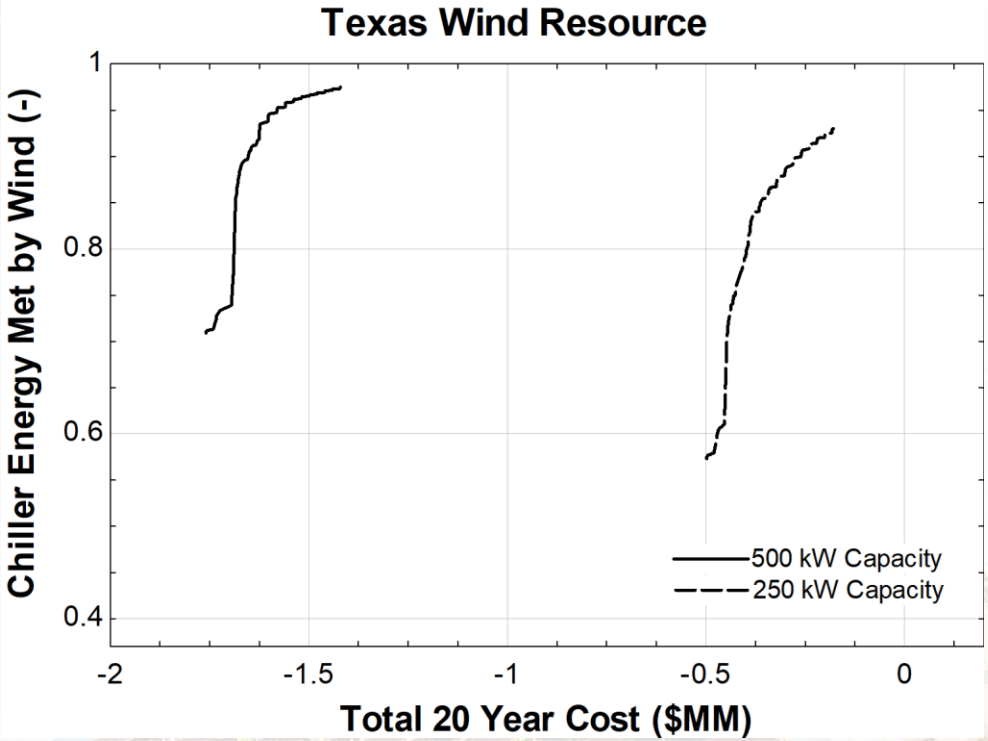




Cool thermal storage concepts (emerging)

Shifts consumption of electricity from periods when renewable energy is not available to periods when renewable energy is available





Will increasing deployment of renewable energy production solve our problems?

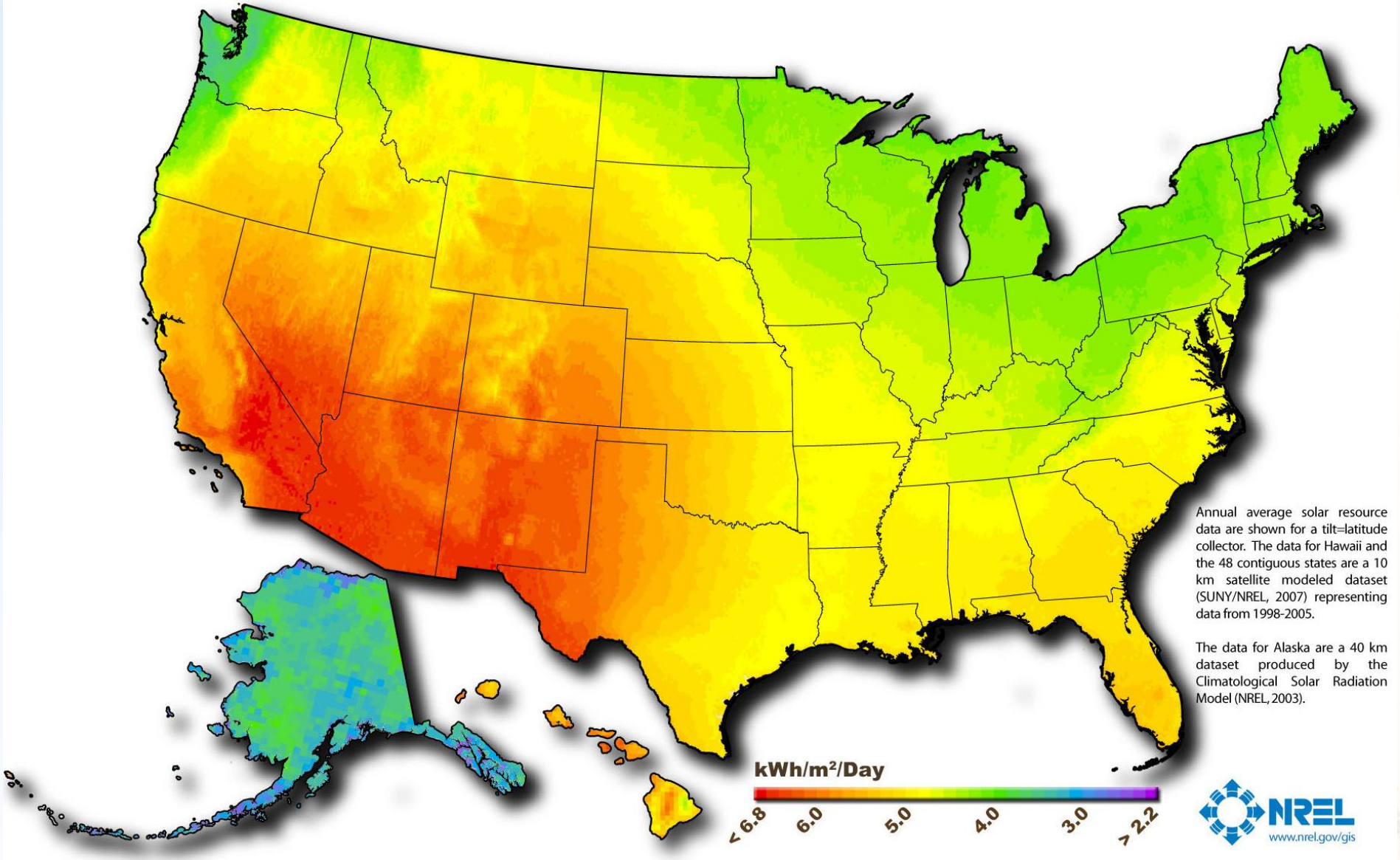
Sources for renewable electricity production

- Solar
  - Photovoltaic
  - Concentrating Solar Power (CSP)
- Wind
- Biomass






Photovoltaic solar resource



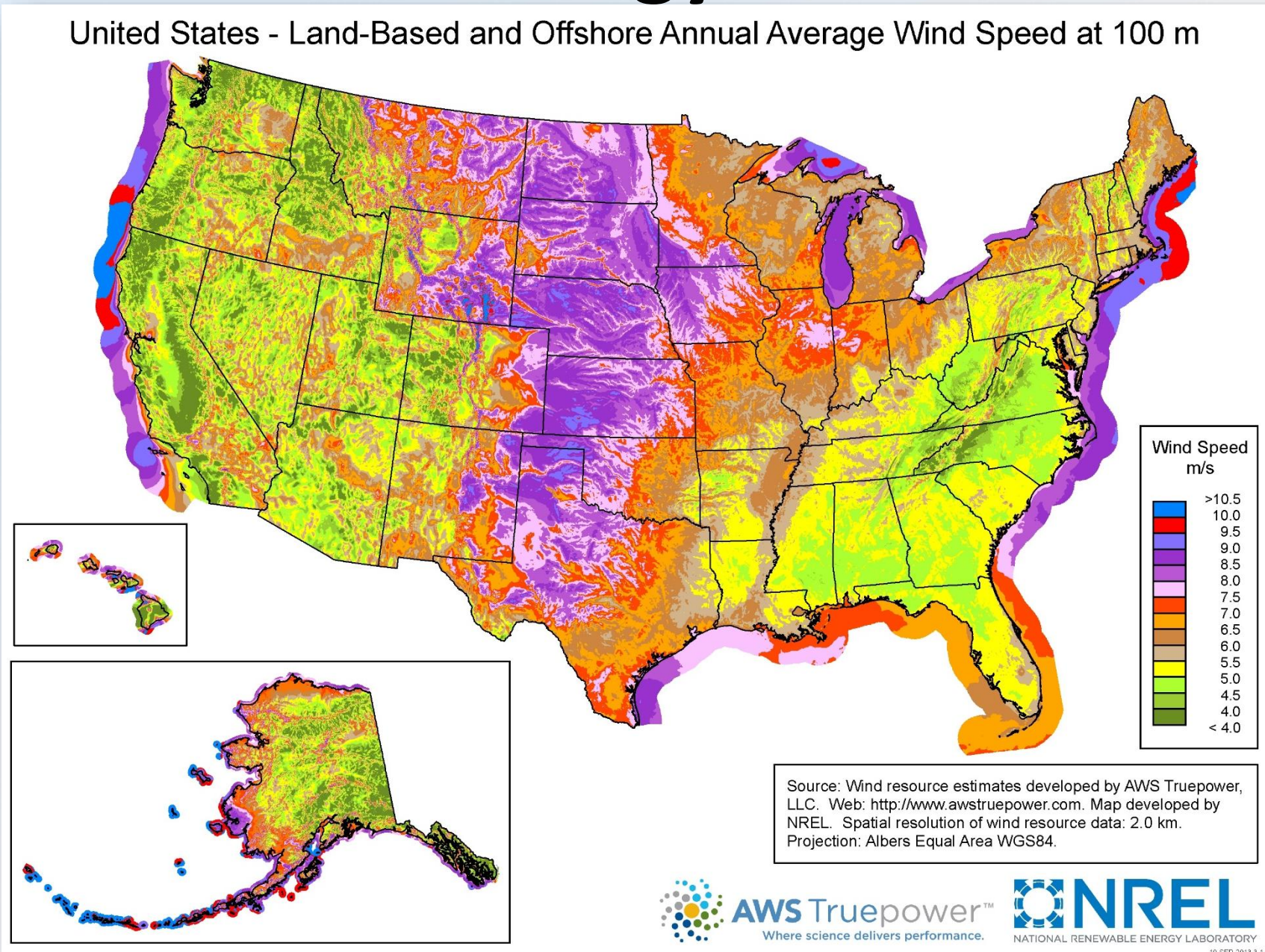
Annual average solar resource data are shown for a tilt=latitude collector. The data for Hawaii and the 48 contiguous states are a 10 km satellite modeled dataset (SUNY/NREL, 2007) representing data from 1998-2005.

The data for Alaska are a 40 km dataset produced by the Climatological Solar Radiation Model (NREL, 2003).

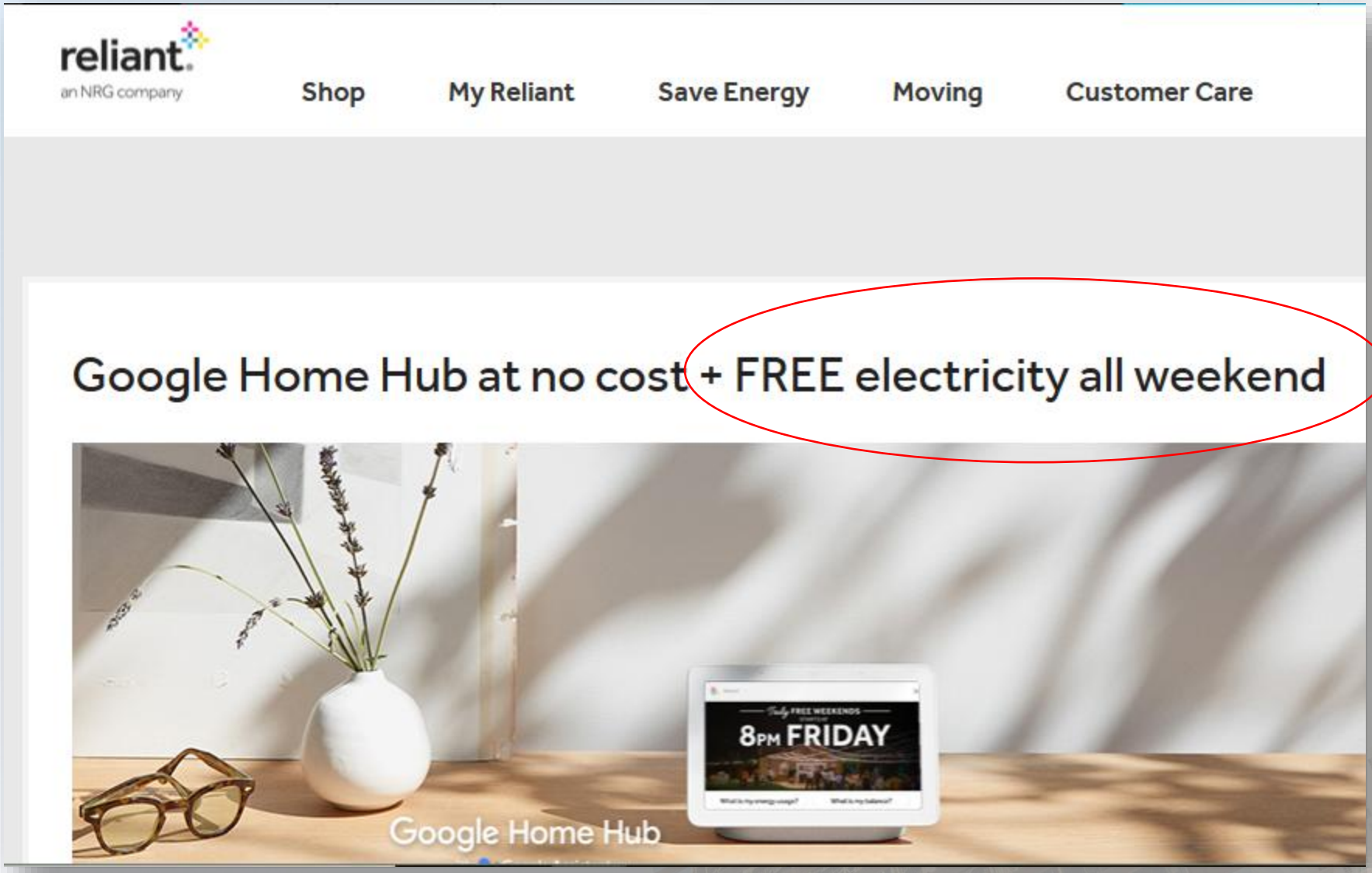
Author : Billy Roberts - October 20, 2008

This map was produced by the National Renewable Energy Laboratory for the U.S. Department of Energy.

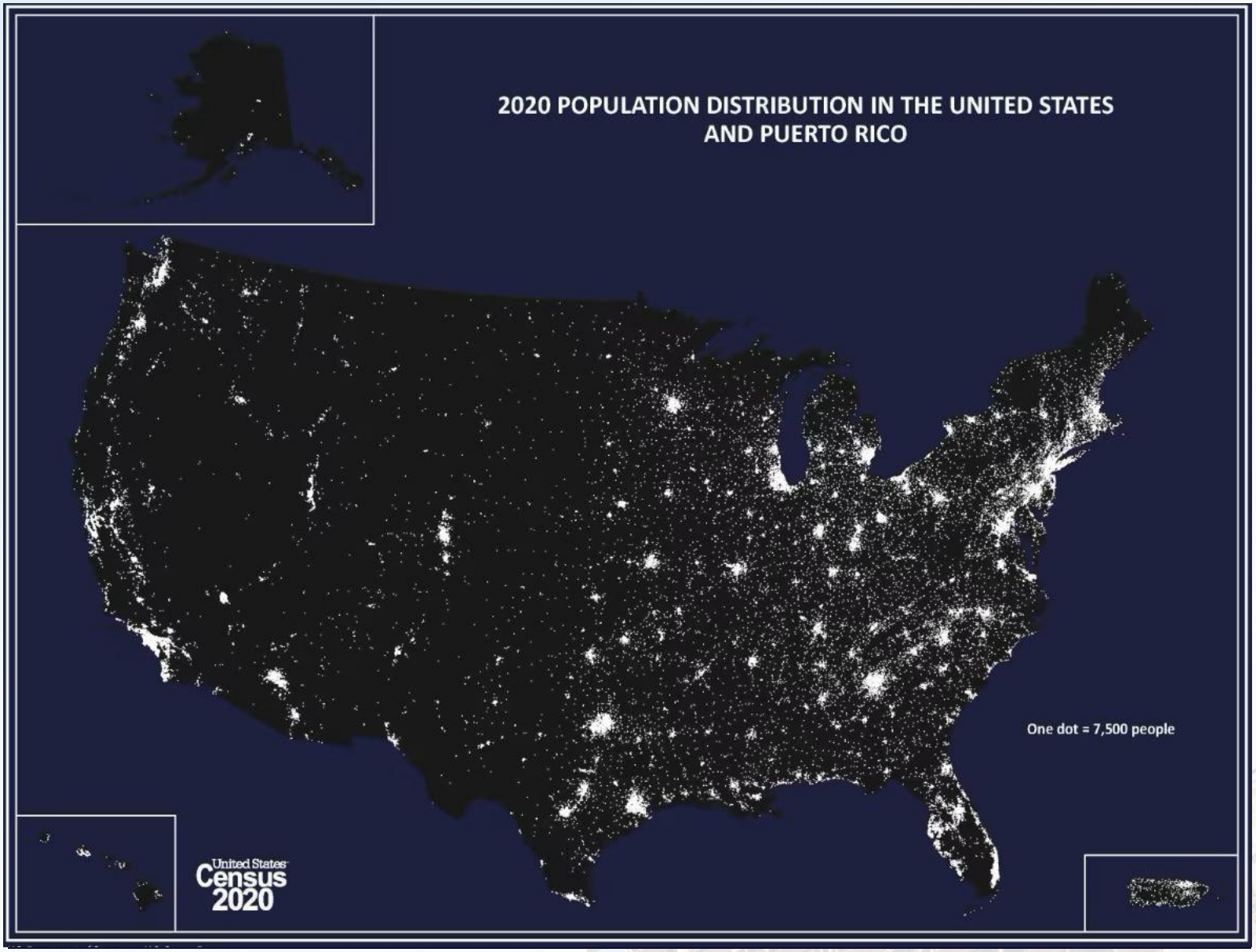
Wind energy resource



Here electricity is free all weekend!



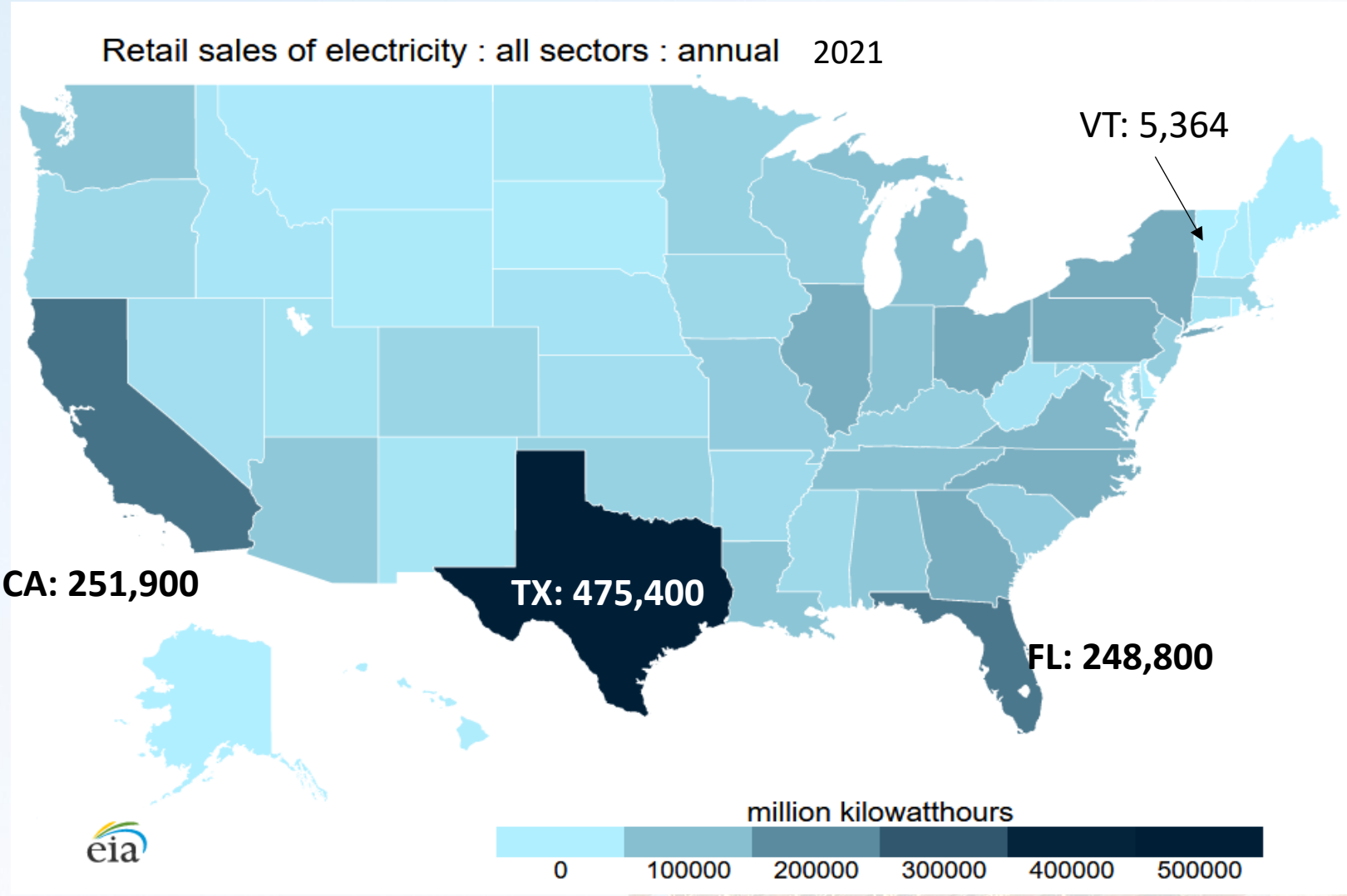
Where is electric power needed?



Prepared by Geography Division, U.S. Department of Commerce Economics and Statistics Administration U.S. Census Bureau

Which state in the U.S. has the highest electricity consumption?

Where is electricity needed?

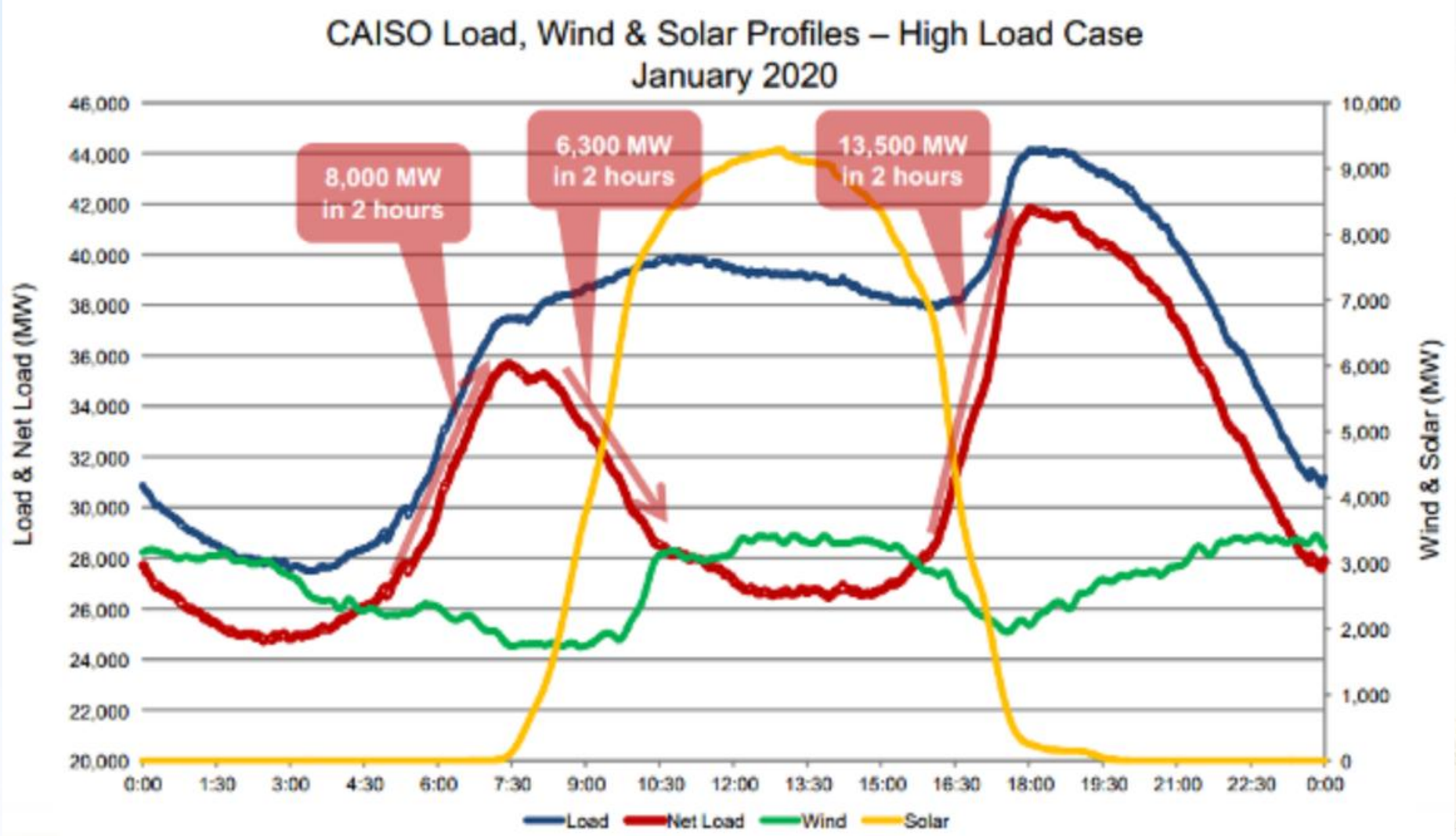


Key renewable energy production characteristics

- Resource and the associated renewable energy production varies geographically
- Greatest resource not necessarily coincident with regions having greatest power demands
- Energy resource is intermittent
- For many locations, wind and PV are complementary resources

There are other dimensions to the challenges with increasing renewable energy utilization:

Balancing intermittent electricity generators with increasingly dynamic electric demands from end-users



The “duck” curve

~8,000 MW
morning ramp rate
(morning start-up demand with no or low renewables)

~11
afternoon ramp rate
(increasing demand while renewables are declining)

~8,000+ MW ramp rate
(decreasing demand as renewables are increasing)

Tail

Belly

Head

start

start

stop

2012 (actual)

2013

2014

2015

2016

2017

2018

2019

2020

Megawatts

30,000

28,000

26,000

24,000

22,000

20,000

18,000

0

12am

12pm

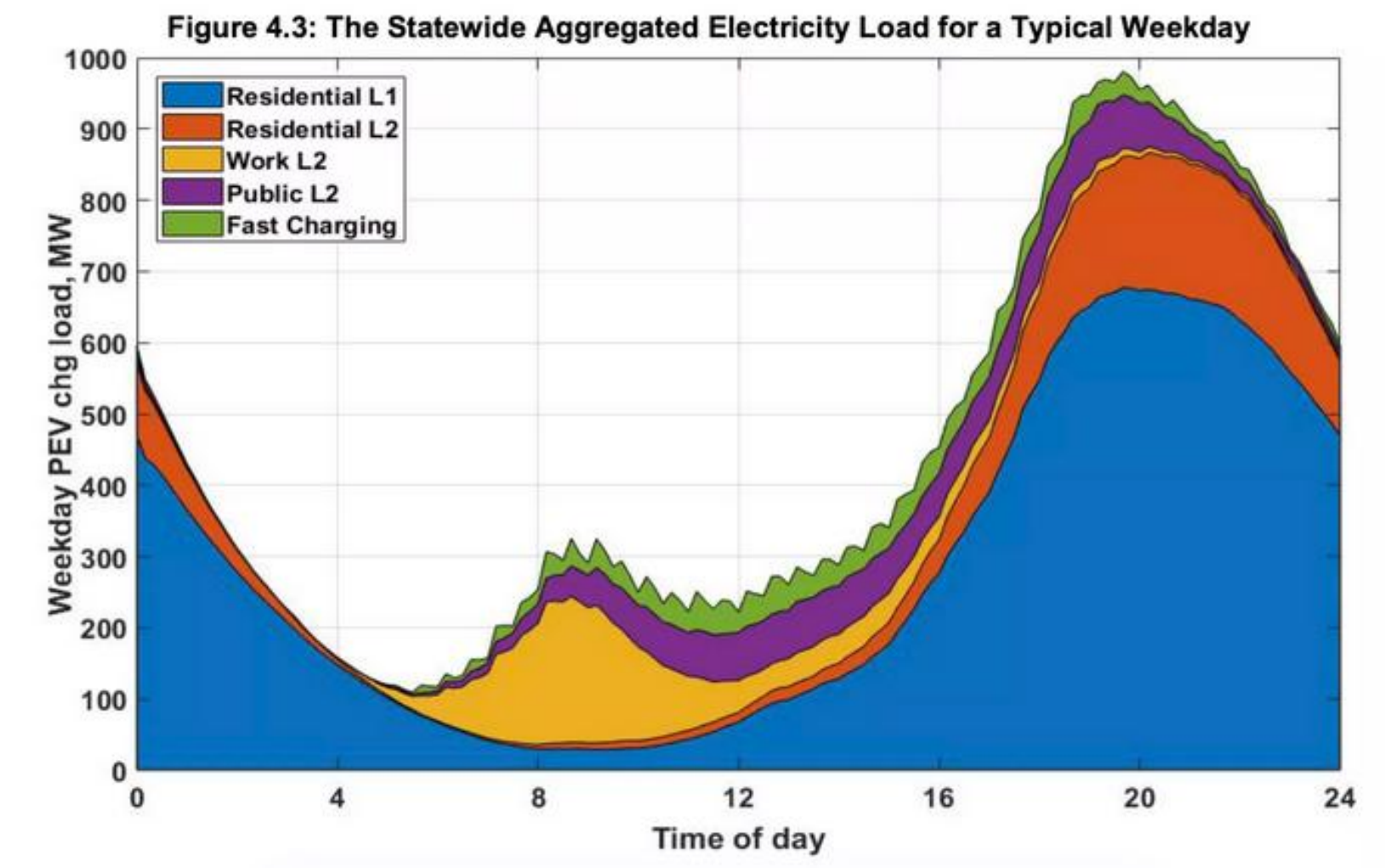
3pm

6pm

9pm

Hour

The “dragon” curve



The California Energy Commission's report “California Plug-In Electric Vehicle Infrastructure Projections: 2017-2025”

New utility operating “issues” with increased renewable energy generation

- Extremely high ramp rates
  - Requires ISO to bring on or shutdown generation resources quickly to meet increasing or decreasing demand
  - Traditional generation assets cannot meet these ramp rates
- Overgeneration
  - More electricity produced than needed for instantaneous demand
  - Renewables will be idled when baseload generation is encroached
- Intermittent production utilities do not control
  - Intermittent renewable energy production from NUGs

Strategies to cope

- Increased end-use energy efficiency
  - Every reduction in kW and kWh is less power/energy needing to be generated

Duck on a diet

- Demand response
  - DR is a tool for load management that enables a utility to call for end-use demand reduction when needed
- Energy storage
  - Cool thermal storage (most effective)
  - Battery storage

"Flatten the duck"

- Increase flexibility of generation
  - Power production that can cycle more frequently

"Fatten the duck"

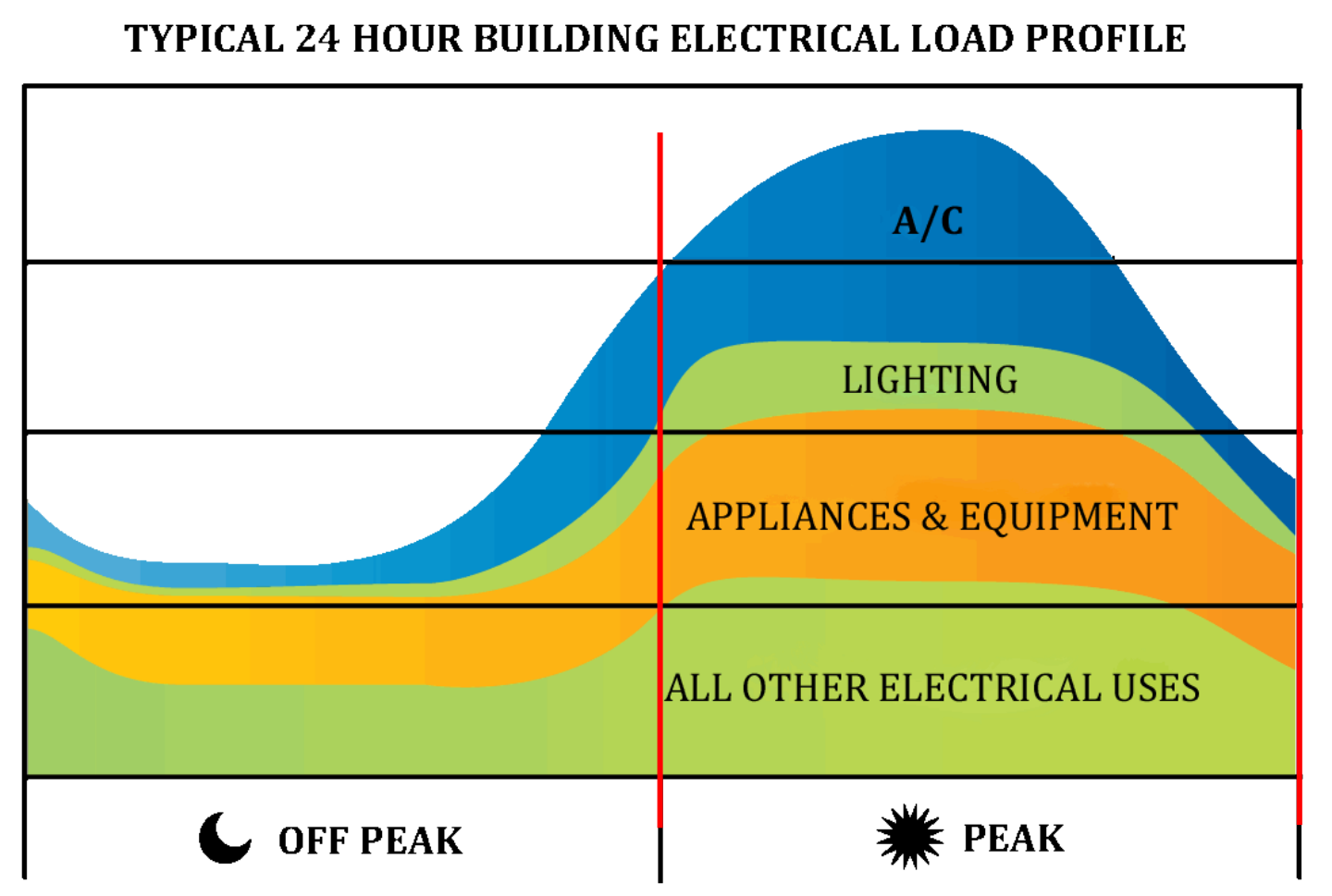
- Microgrids?

Ducklings

For buildings, thermal energy storage is the best choice

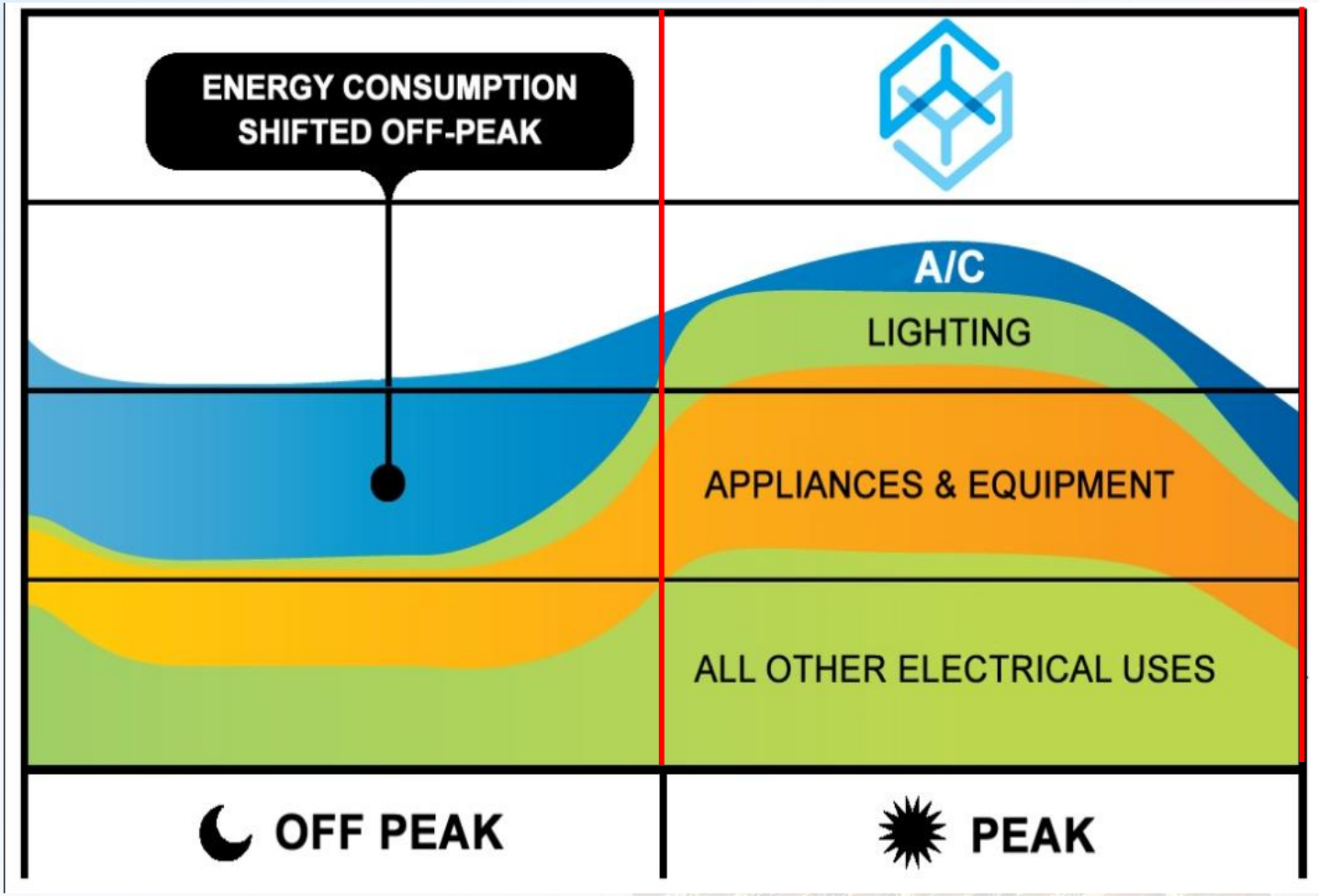
- A building's cooling system
  - Is a significant energy user – particularly in hot humid climates
  - Dominates building electrical demand
- Compared to other storage technologies, TES is
  - More cost-effective
  - Uses off-the-shelf technology
  - More reliable with longer life
  - Compatible with microgrid applications

Commercial building load profile



If A/C load could be shifted off peak, a facility can reduce its electric energy demand and electricity costs (demand and energy).

Thermal storage enables shifting chiller operation to off-peak periods



Design and Utilization of Thermal Energy Storage to Increase the Ability of Power Systems to Support Renewable Energy Resources

ASHRAE RP-1607

Key conclusions from RP-1607

- Buildings equipped w/CTES & appropriate control strategies, enabled increased renewable energy utilization ranging from 10%-50% vs. non-storage cases
- Improvements are consistent across geographic regions and building types
- CTES is cost-effective and available today

Energy Storage Example
University of Nebraska-Lincoln (UNL)

Two **CHW TES** at UNL,

each providing:

1) energy storage, plus

2) peaking capacity for the campus CHW network

UNL East Campus

Storing 16,326 ton·h (12 MWh elec) and shifting up to 4,000 tons (3 MW)

UNL City Campus

Storing 52,000 ton·h (39 MWh elec) and shifting up to 8,333 tons (6.25 MW)

Source: J. Andrepont

Example: 39 MWh at UNL

Storage Element	Lithium-Ion Advanced Batteries (hypothetical)	Chilled Water (CHW) Thermal Energy Storage (TES) (actual, 2017-18)
Peak cooling discharge	not applicable	8,333 tons
Peak electric discharge	6.25 MW	6.25 MW equivalent
Duration at peak disch.	6.24 h	6.24 h
Net storage (thermal)	not applicable	52,000 ton·h
Net storage (electric)	39.0 MWh	39.0 MWh equivalent
Storage unit cap cost	$350/kWh	$100/ton·h
Storage capital cost	**$13.65 million**	**$5.20 million (38% of batteries)**
Full system cap cost	**$27.3 million**	**$11.7 million (43% of batteries)**
Full system unit cap cost	**$700/kWh**	**$225/kWh (43% of batteries)**

Source: J. Andrepont

Conclusions

- Electricity demand is expected to grow significantly in the next decade
- Air conditioning is a significant proportion of peak demand
- AC systems are often the building's single largest electric energy consumer
- TES is the most cost-effective technology to decouple production of cooling from electricity-intensive demand
- TES will enable a greater fraction of our electricity consumption to originate from renewables – including microgrid applications

Questions?

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