Powering with Renewable Resources: Thermal Energy Storage

Douglas Reindl, Ph.D., P.E.
Professor, Department of Mechanical Engineering
University of Wisconsin-Madison
E-mail: dreindl@wisc.edu

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Learning Objectives

1. Understand the impacts that increasing renewable energy production is having on the utility grid.

2. Recognize the acute need for energy storage with increased renewables.

3. State the advantages/disadvantages of traditional batteries for grid-scale energy storage .

4. Consider in what circumstances thermal energy storage (TES) may be most appropriate.

5. Recognize how TES systems can enable greater amounts of renewable energy production on the grid.

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Renewable Energy

☐ **What is it?**

☐ **What are impacts of increasing renewables, as an intermittent generation asset, on the grid?**

☐ **Are there constraints?**

☐ **If so, how can constraints be mitigated?**

Renewable energy

“energy from sources that are naturally replenishing but flow-limited; renewable resources are virtually inexhaustible in duration but limited in the amount of energy that is available per unit of time”

Source: U.S. Energy Information Administration

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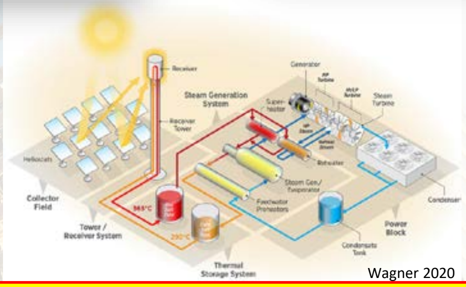
Sources for renewable electricity production

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



Wagner 2020

Renewables, inherently, are diffuse & intermittent resource that varies geographically

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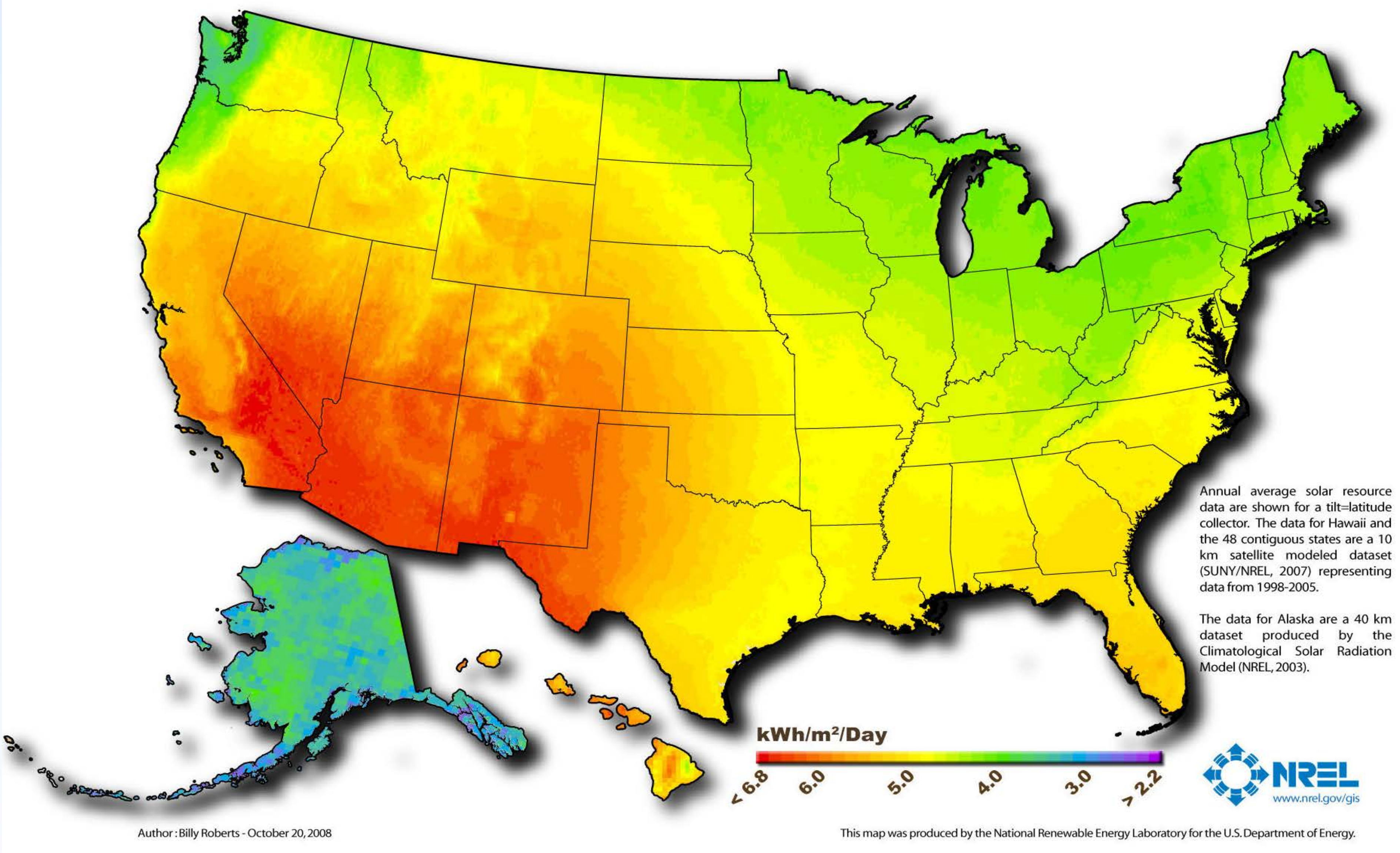
Photovoltaic solar resource



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.

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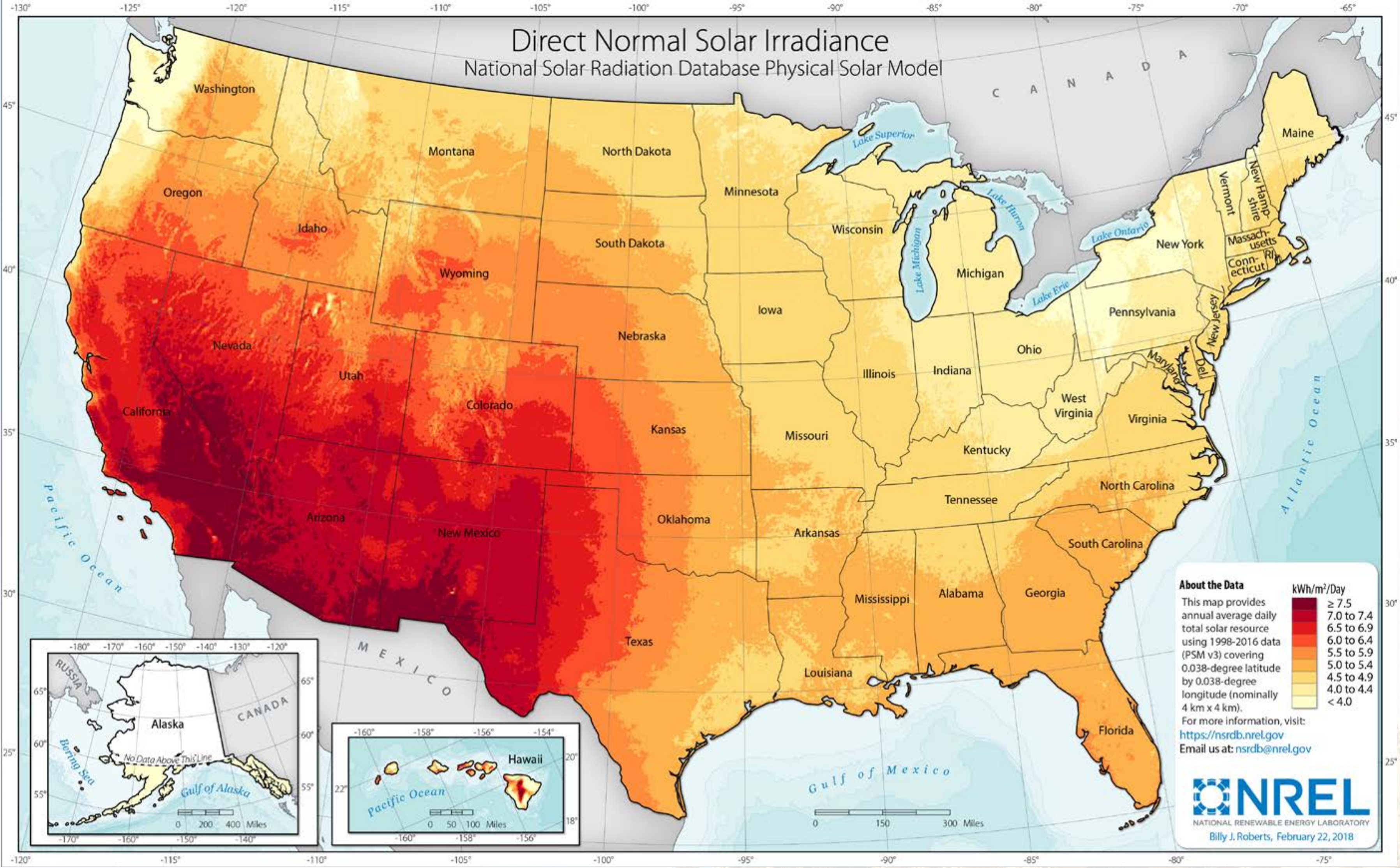
Concentrating solar power resource



Direct Normal Solar Irradiance

National Solar Radiation Database Physical Solar Model

About the Data

This map provides annual average daily total solar resource using 1998-2016 data (PSM v3) covering 0.038-degree latitude by 0.038-degree longitude (nominally 4 km x 4 km).

For more information, visit: https://nsrdb.nrel.gov

Email us at: nsrdb@nrel.gov

NATIONAL RENEWABLE ENERGY LABORATORY

Billy J. Roberts, February 22, 2018

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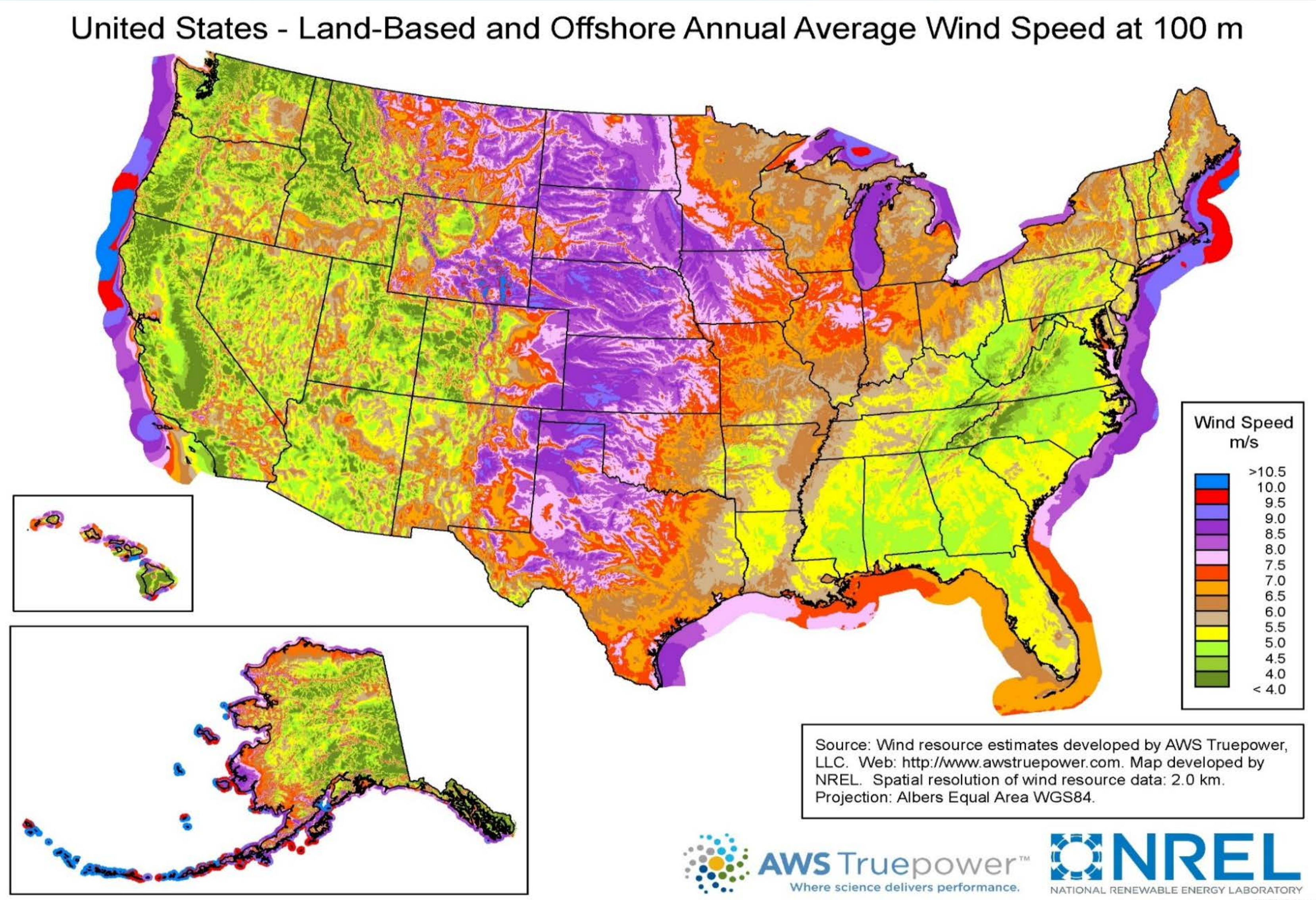
Wind energy resource



United States - Land-Based and Offshore Annual Average Wind Speed at 100 m

Source: Wind resource estimates developed by AWS Truepower, LLC. Web: http://www.awstruepower.com. Map developed by NREL. Spatial resolution of wind resource data: 2.0 km. Projection: Albers Equal Area WGS84.

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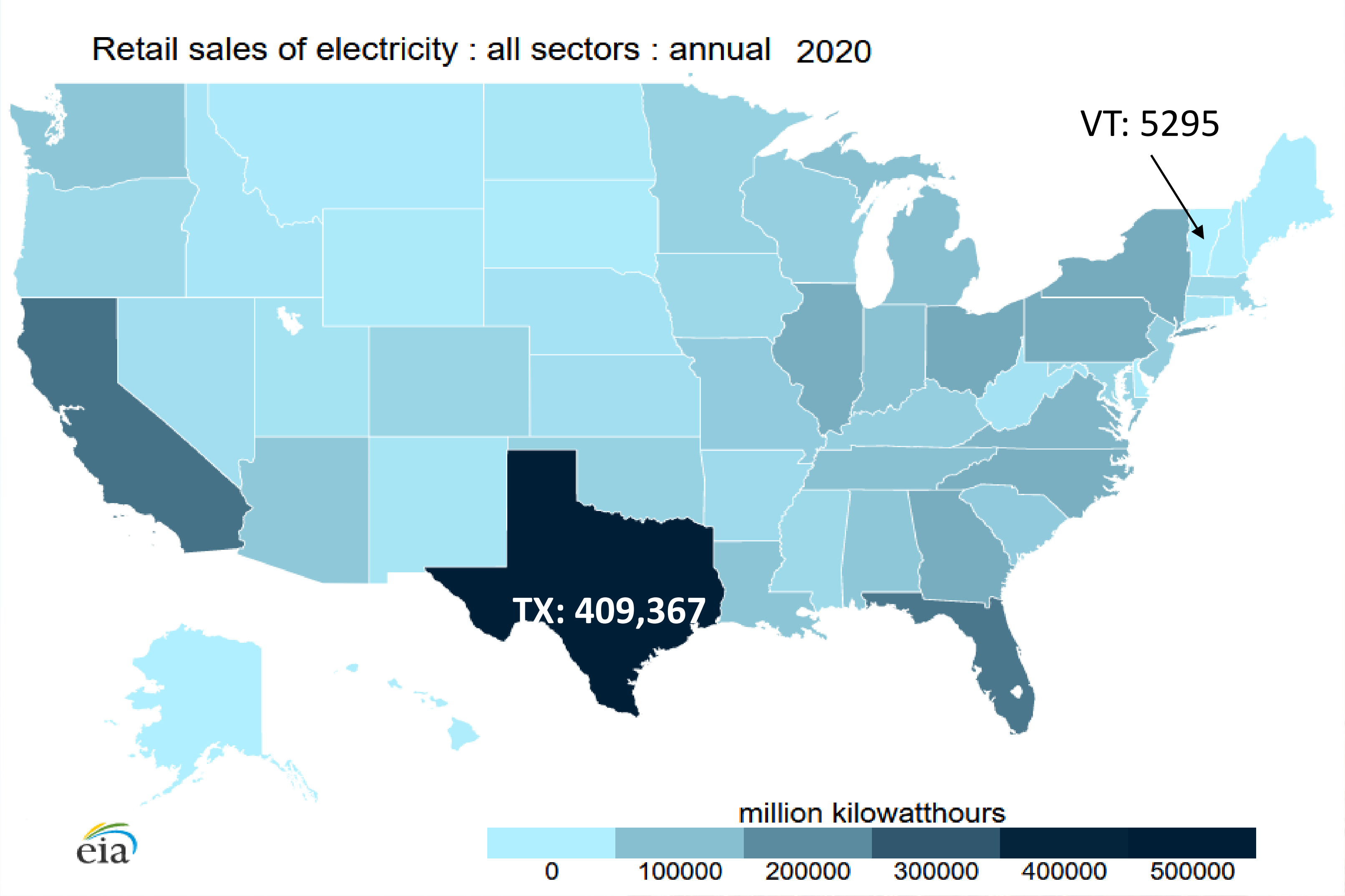
Where is electricity needed?



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Renewable energy

What is it?

What are impacts of increasing renewables, as an intermittent generation asset, on the grid?

Are there constraints?

If so, how can constraints be mitigated?

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Renewable energy production characteristics

- Resource / production capability varies geographically
- Greatest resource not necessarily coincident with regions having greatest electrical power demand / consumption
- Energy resource is inherently intermittent
- For many locations, wind and PV are complementary resources

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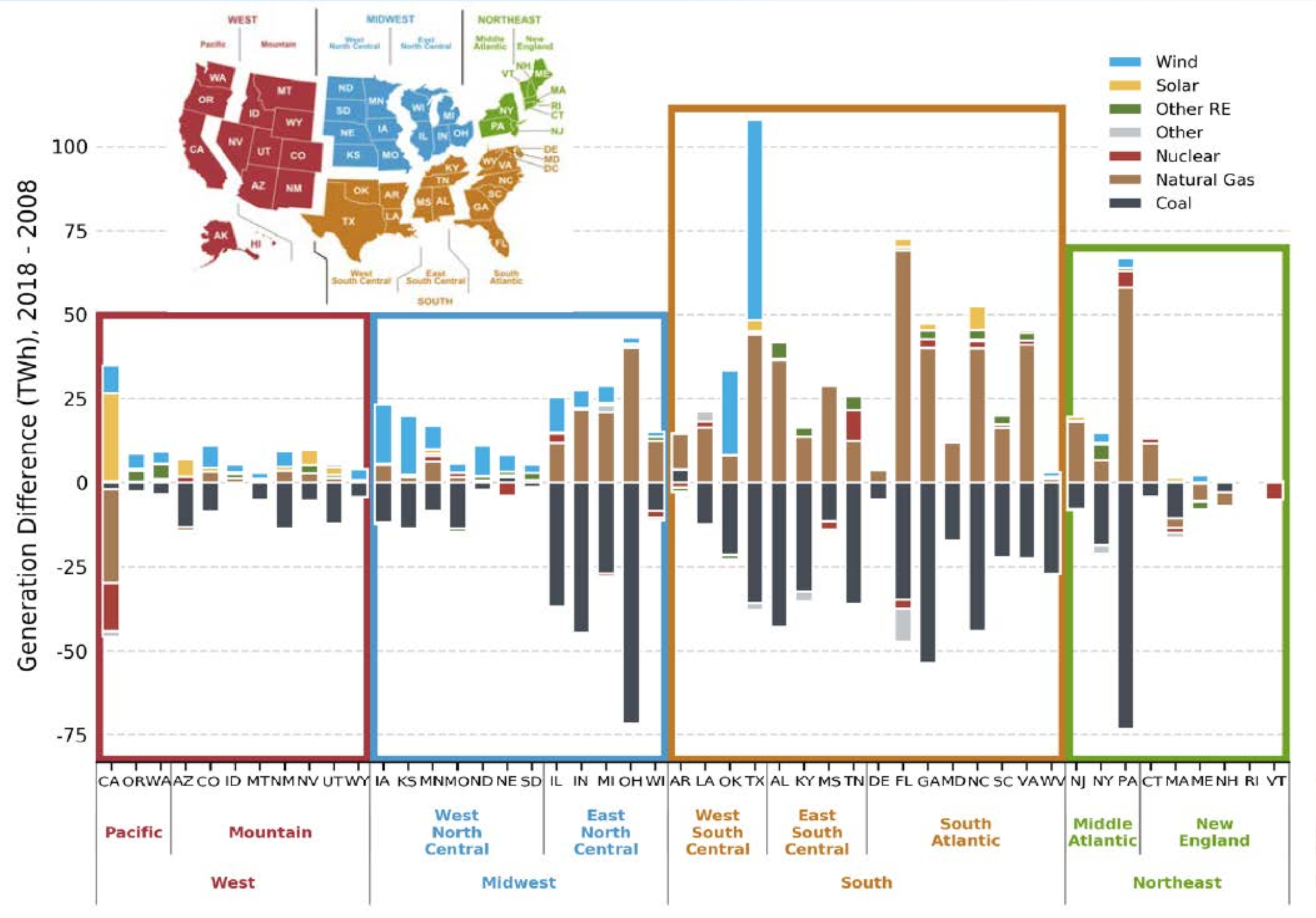
Changes in electricity generation have been occurring



Source: “2019 Standard Scenarios Report: A U.S. Electricity Sector Outlook”, Cole et al., NREL December 2019.

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What issues will arise as we increase deployment of renewable energy production?

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Electric utility systems are complex

- Electric utilities must simultaneously match the generation and transmission/distribution of electricity to meet instantaneous electric demands by customers
  - Production deficit = frequency falls
  - Production surplus = frequency increases

Frequency deviations leads to grid instability

- Electric demands are highly dynamic and not directly controllable by utilities
- Utilities must also have sufficient reserve margins for generation to meet reliability needs

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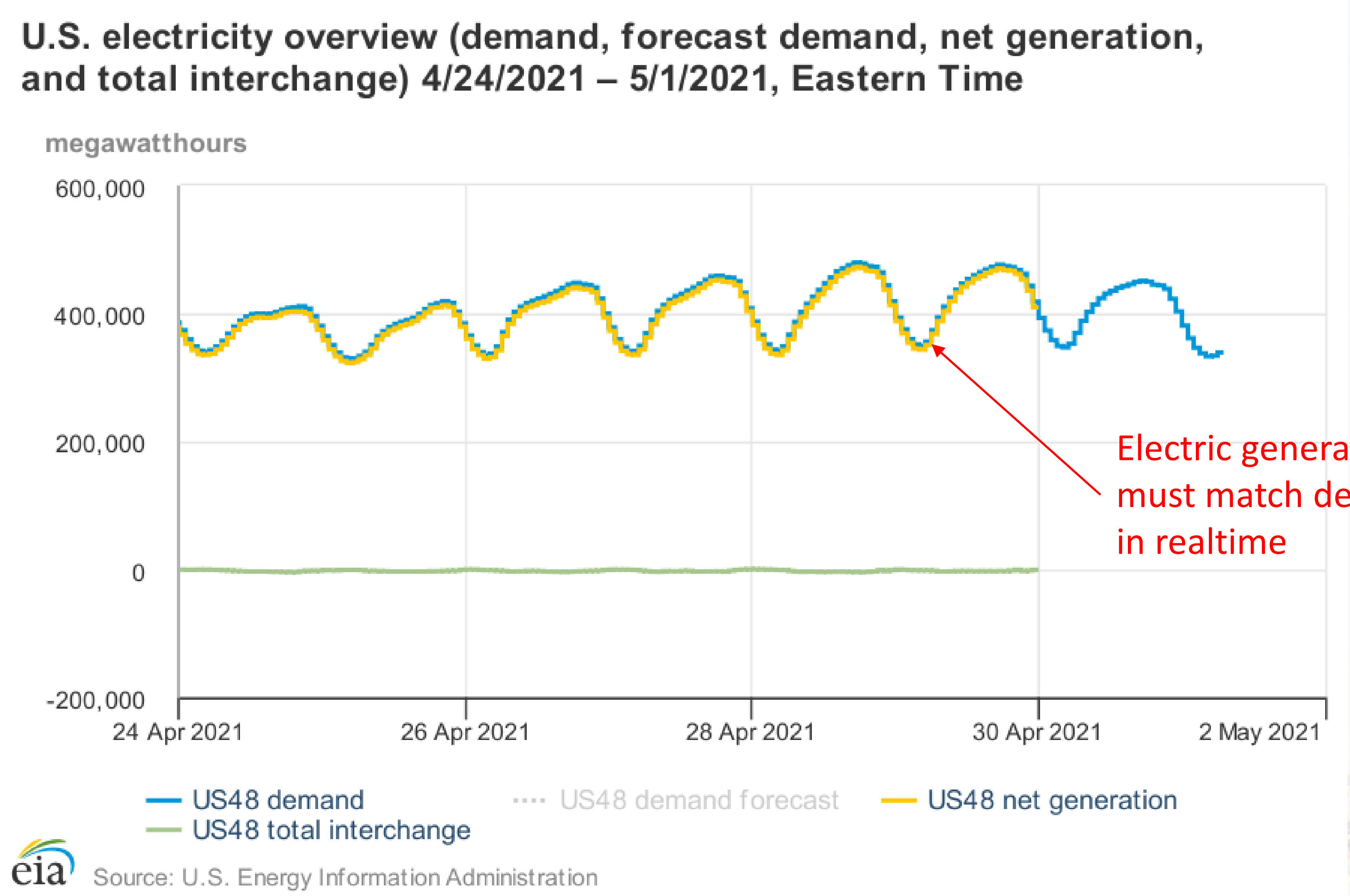
Matching generation with demand



U.S. electricity overview (demand, forecast demand, net generation, and total interchange) 4/24/2021 – 5/1/2021, Eastern Time

Source: U.S. Energy Information Administration

Electric generation must match demand in realtime

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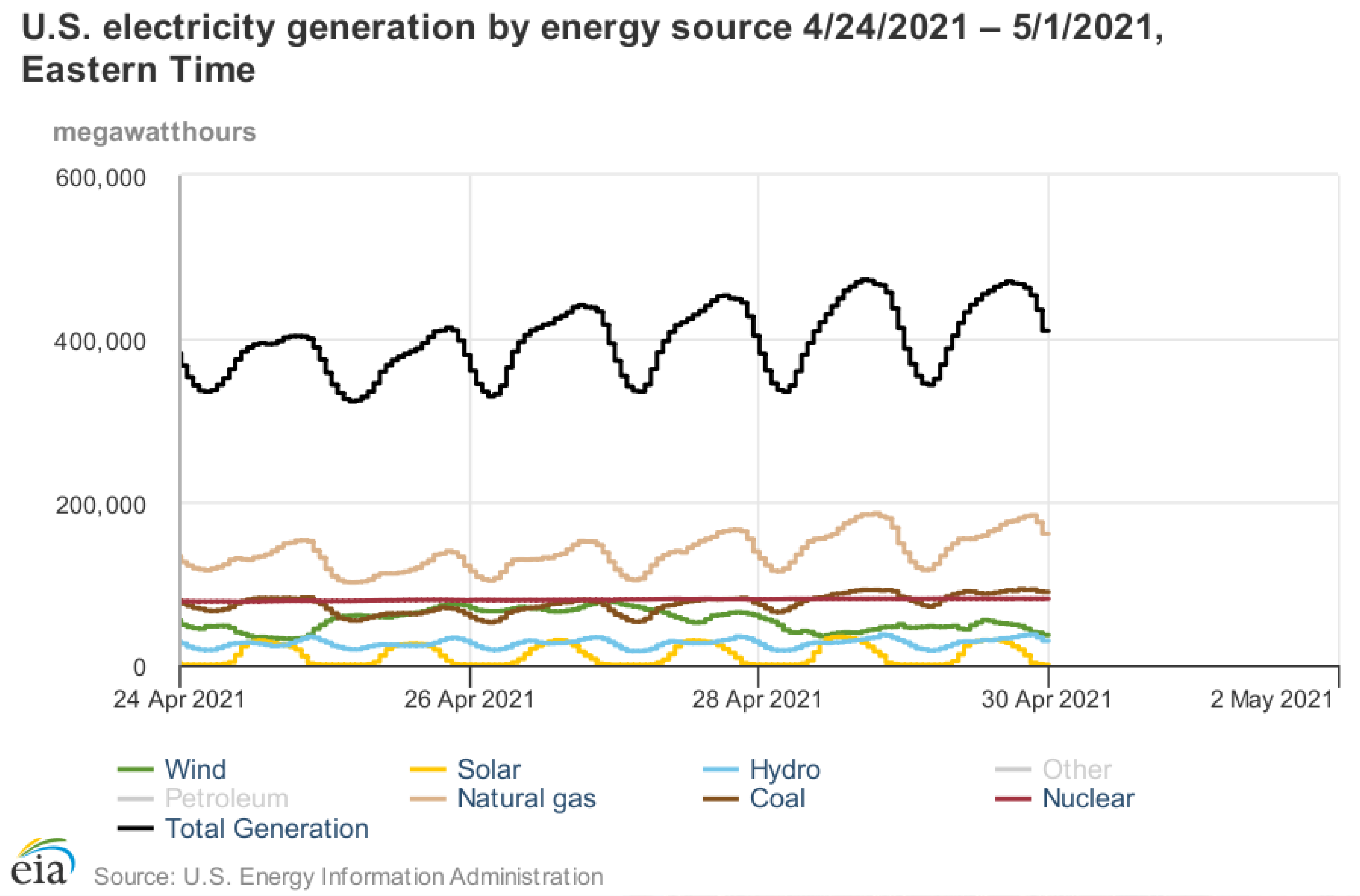
Sources of generation to meet demand



Source: U.S. Energy Information Administration

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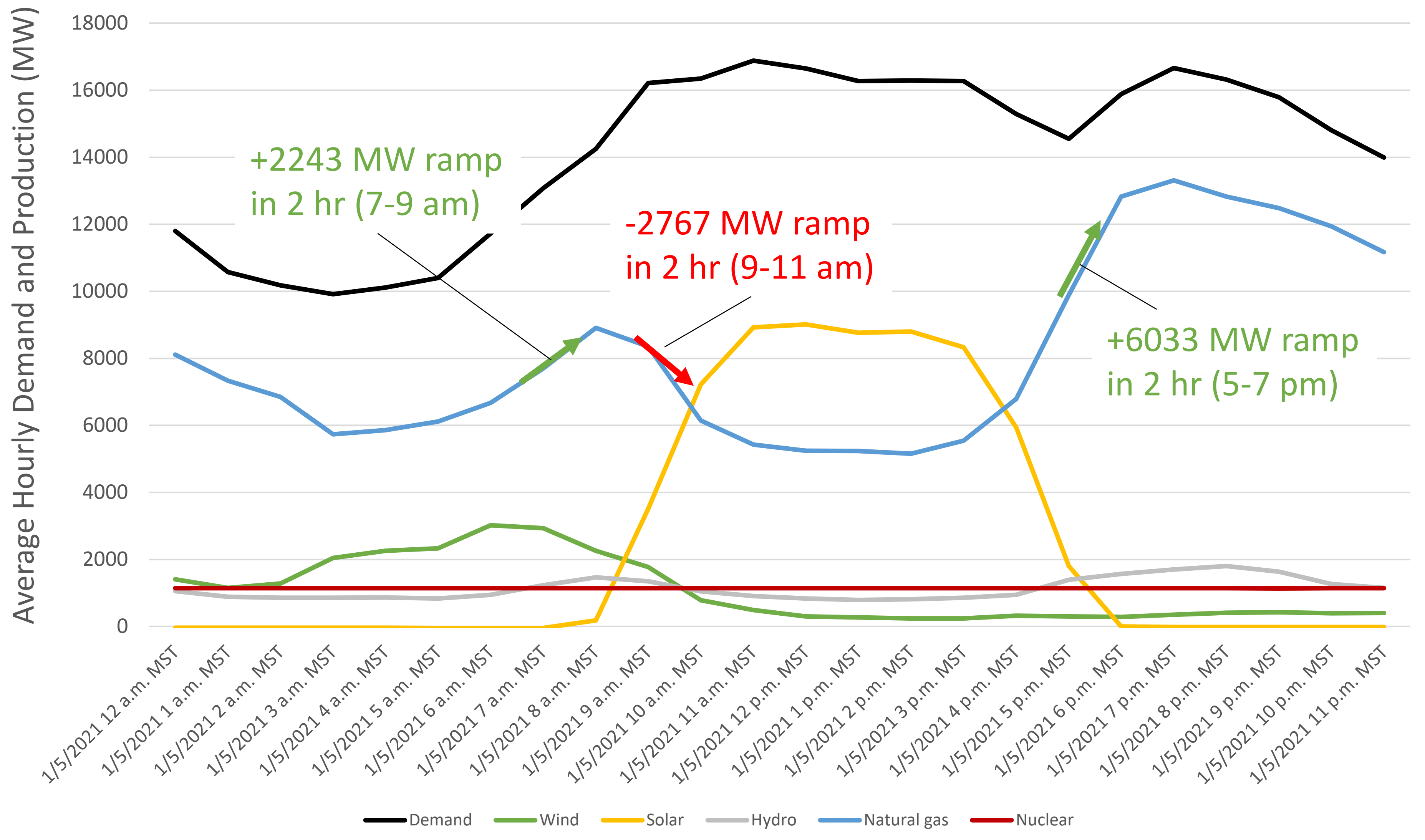
California Independent System Operator Data



Source: [EIA-930, Hourly and Daily Balancing Authority Operations Report]()

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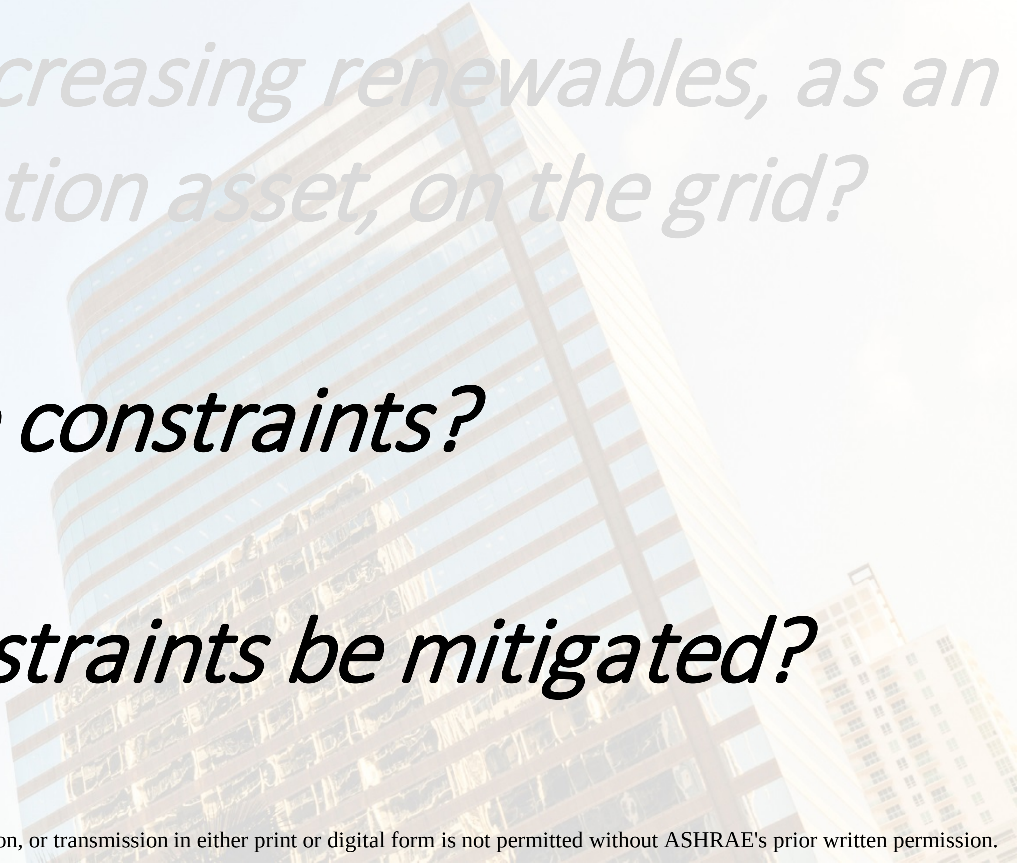
Renewable energy



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Let's look at one example:

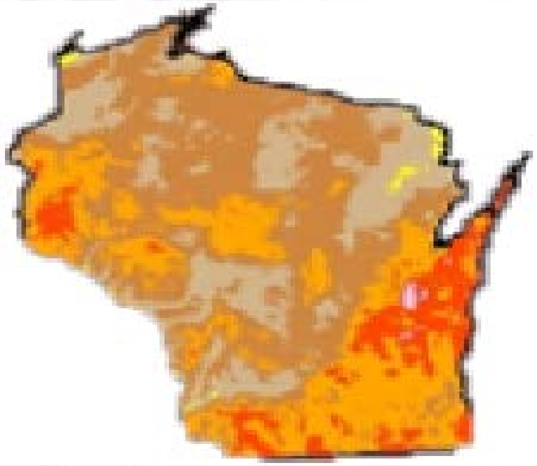
How effective would a large-scale deployment of PV be in Wisconsin?

PV Resource

Ok but not great

vs.

Wind Resource



Wind resource is good!

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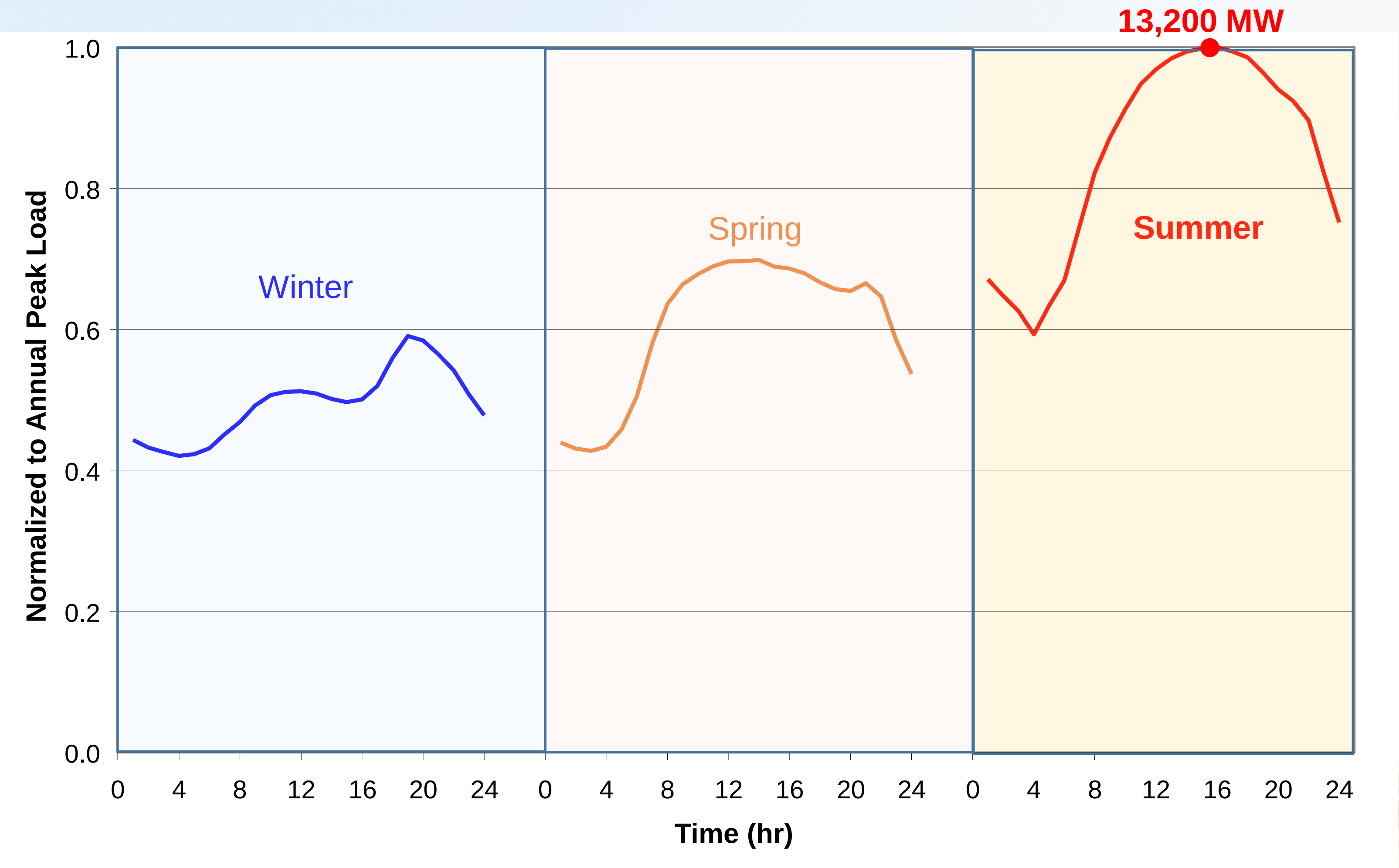
The aggregate demand for electricity in WI peaks at 13,200 MW in the summer



Source: "Assessment of high penetration of solar photovoltaics in Wisconsin", Myers, Klein, and, Reindl, *Energy* Policy, 2010

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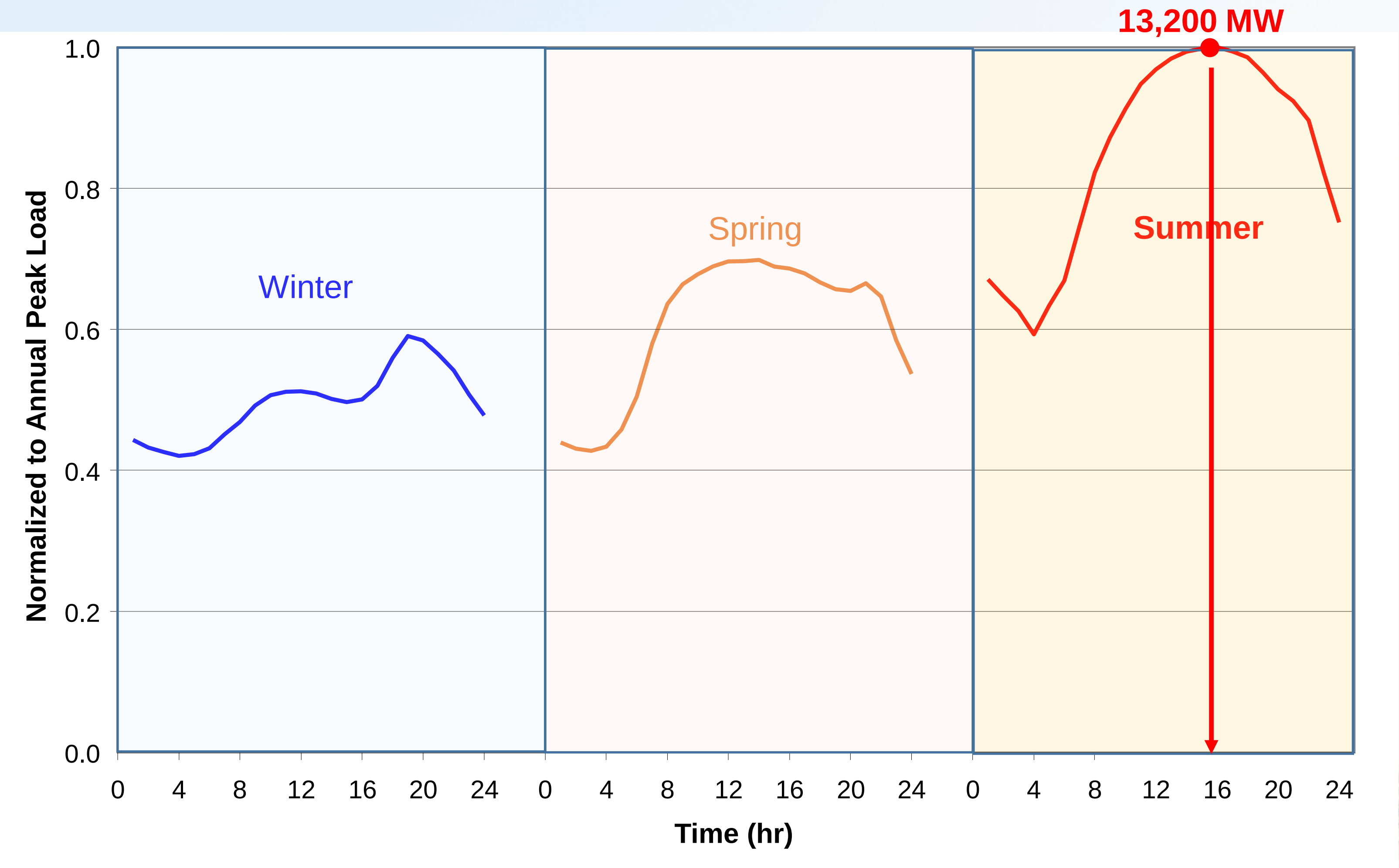

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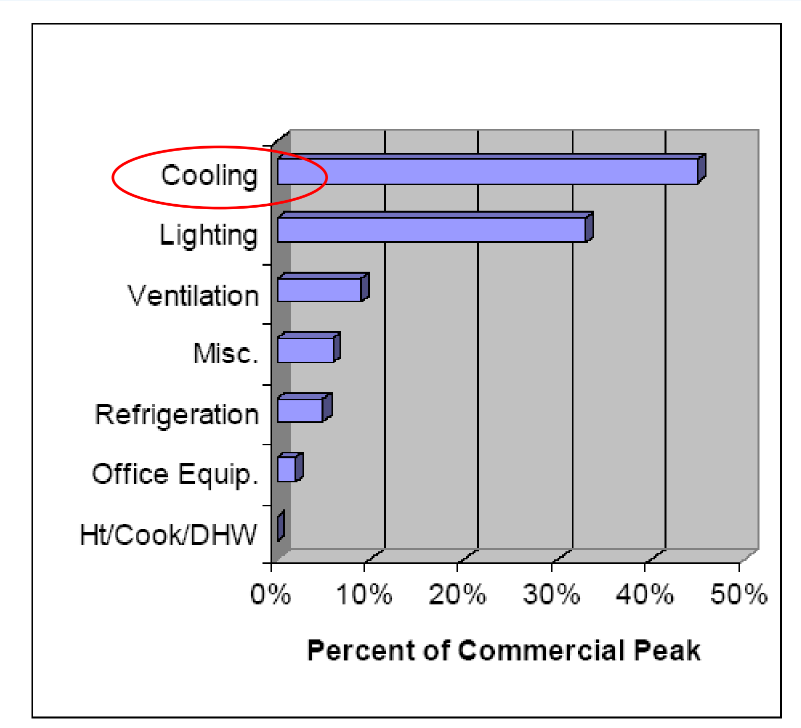
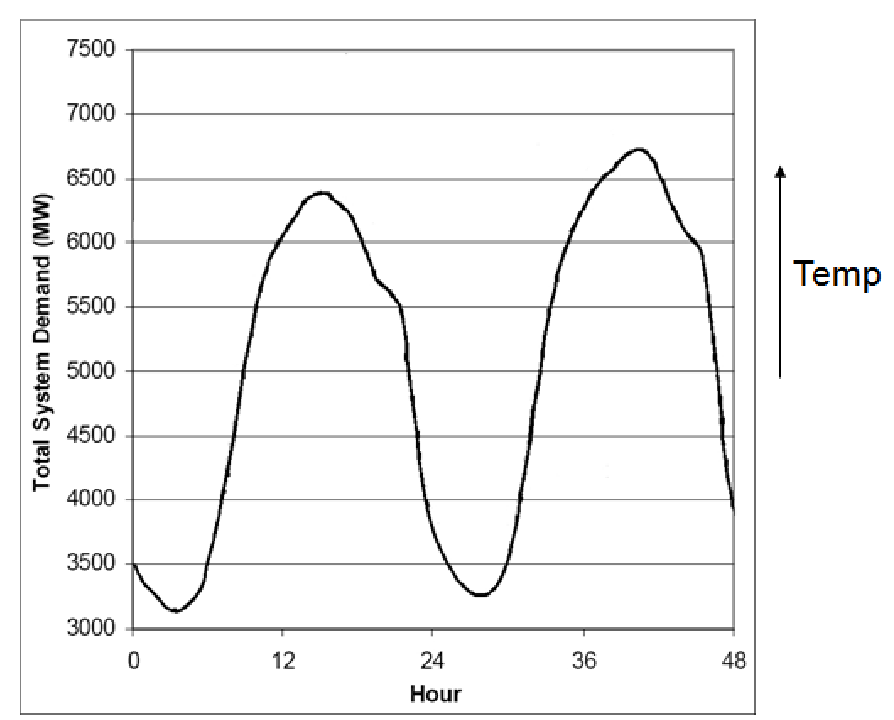
What is driving the peak electricity demand?

Commercial building electric demands



As ambient temperature increases, peak electric demand increases.



Building air conditioning systems are principally responsible for driving peak demand!

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

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

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What do you think?

If 6,600 MW of PV (50% of aggregate peak demand) were installed tomorrow, how much would the net peak electricity demand to utilities be decreased?

- **A. 5%**
- **B. 15%**
- **C. 25%**
- **D. 50%**

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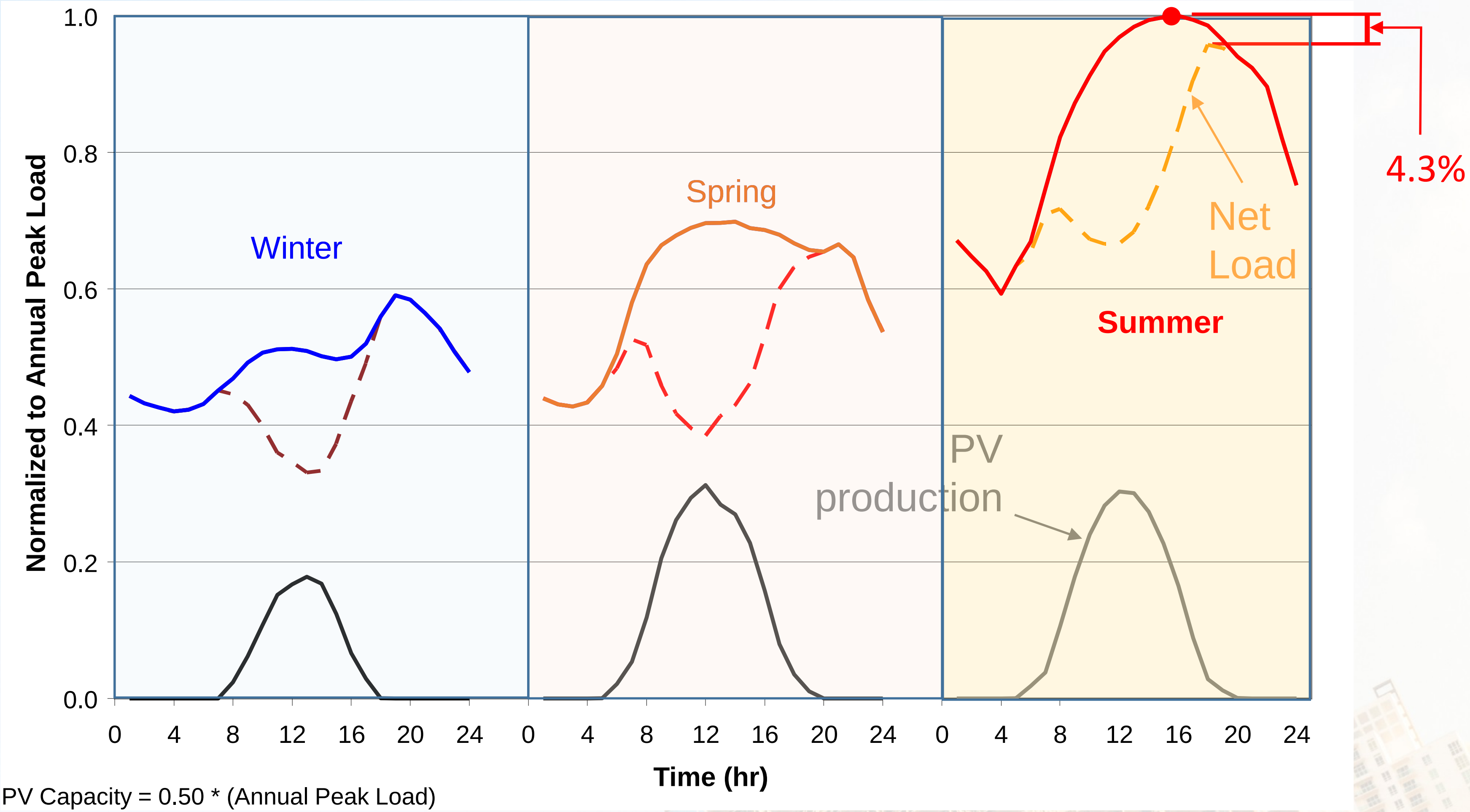
Fundamentally, there is a mismatch between electric demand and supply by renewable energy resources



PV Capacity = 0.50 * (Annual Peak Load)

Net Load = Load – PV Generation

Source: "Assessment of high penetration of solar photovoltaics in Wisconsin", Myers, Klein, and, Reindl, *Energy* Policy, 2010

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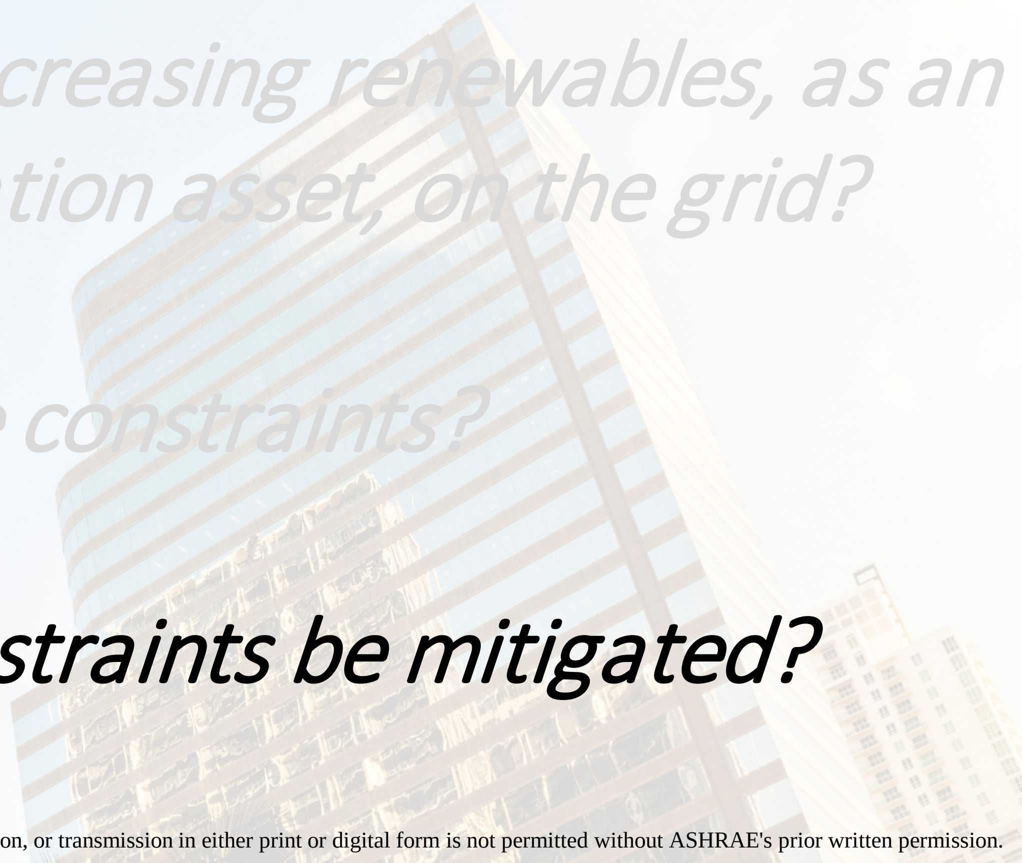
Renewable energy



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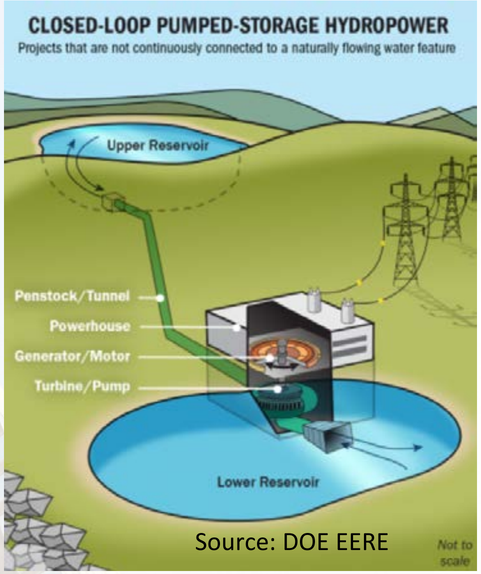
Increasing Deployment of Renewables Requires Energy Storage

- Utility-scale
  - High temperature thermal storage (CSP)
  - Battery storage (PV & wind)
  - Pumped hydro
- End-user
  - Thermal energy storage (air-conditioning)
  - Battery storage
  - Flywheel
- Other storage technologies



Source: DOE EERE

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Energy Storage Provides Flexibility

- Decouples demand from supply
  - Allows "production" of storage when
    - Resources are available
    - Costs are low

- Affords potential downsizing for some equipment
- Enhances reliability/redundancy
- Potentially increases end-use operating efficiency

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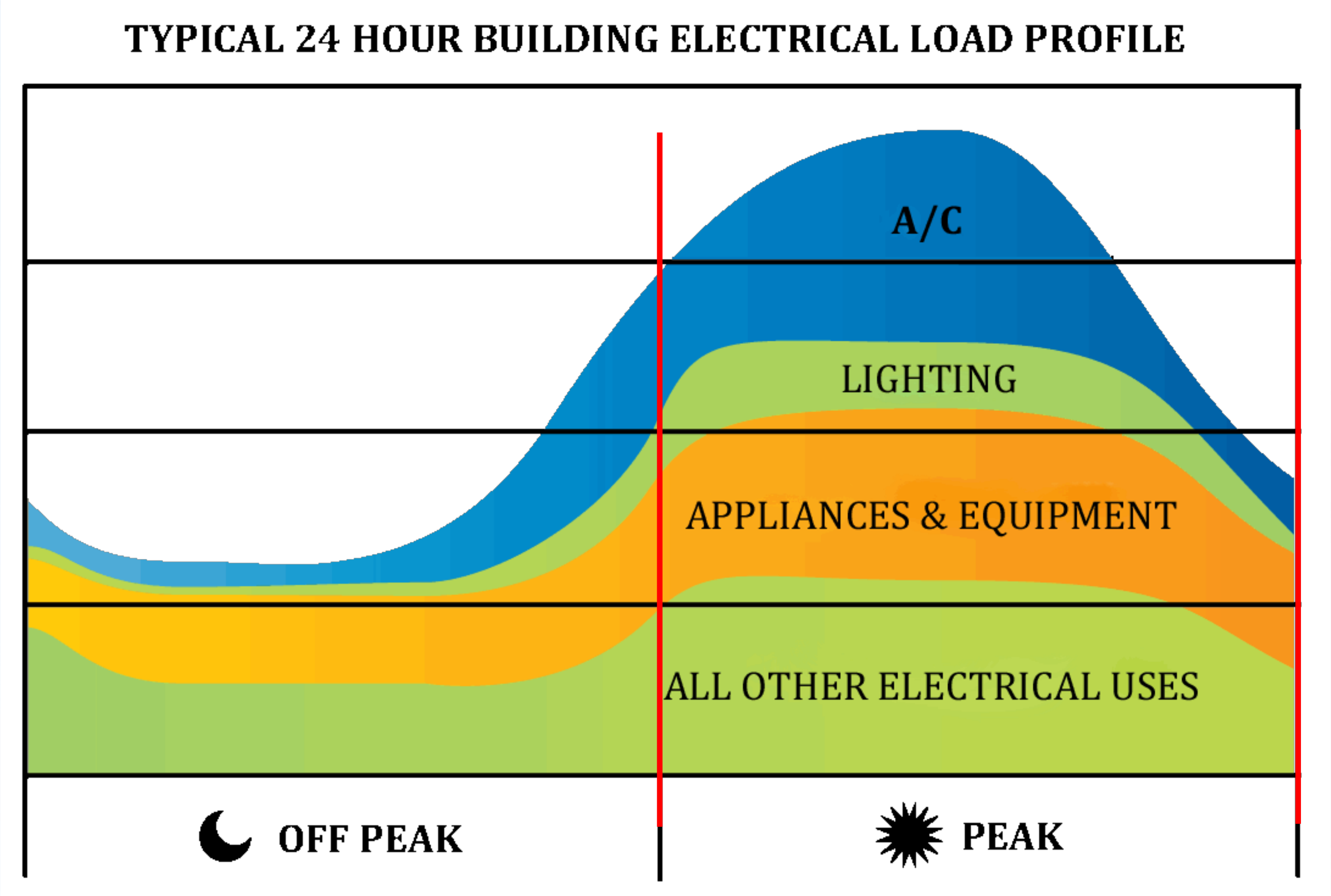
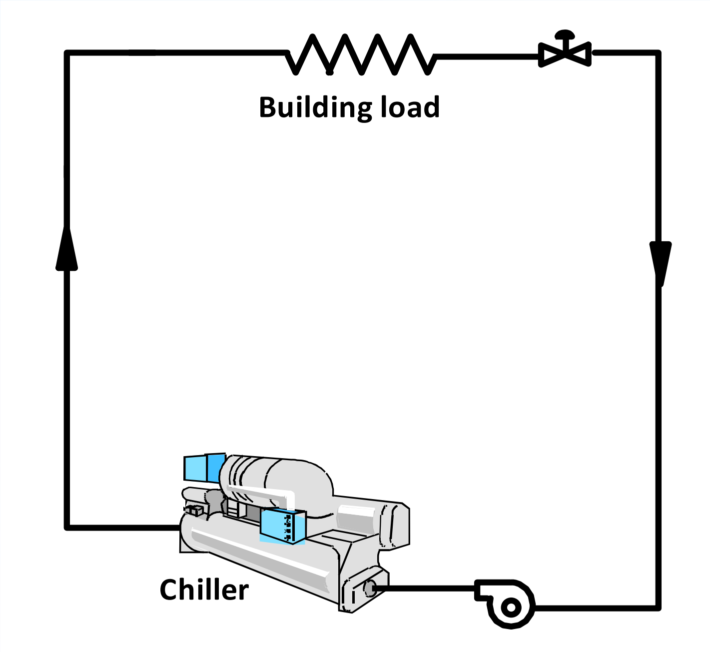
Commercial Building Load Profile

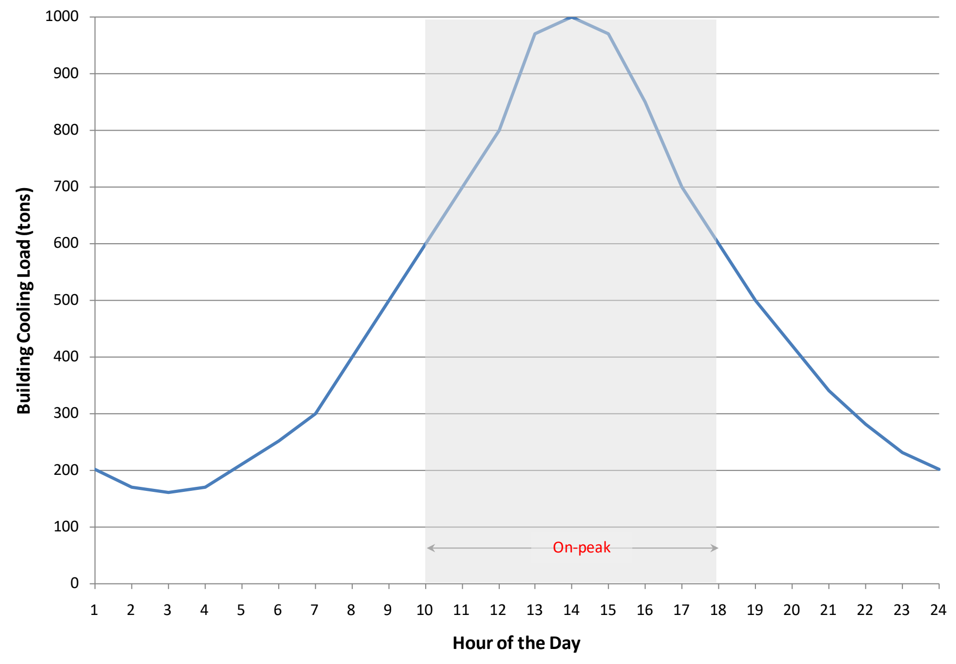


If A/C load could be shifted off peak, a facility can reduce its electric energy demand and electricity costs (demand and energy).

Typical Building Chilling System

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





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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 & consumption
- Compared to other storage technologies, TES is
  - More cost-effective
  - Uses off-the-shelf technology
  - More reliable with longer life

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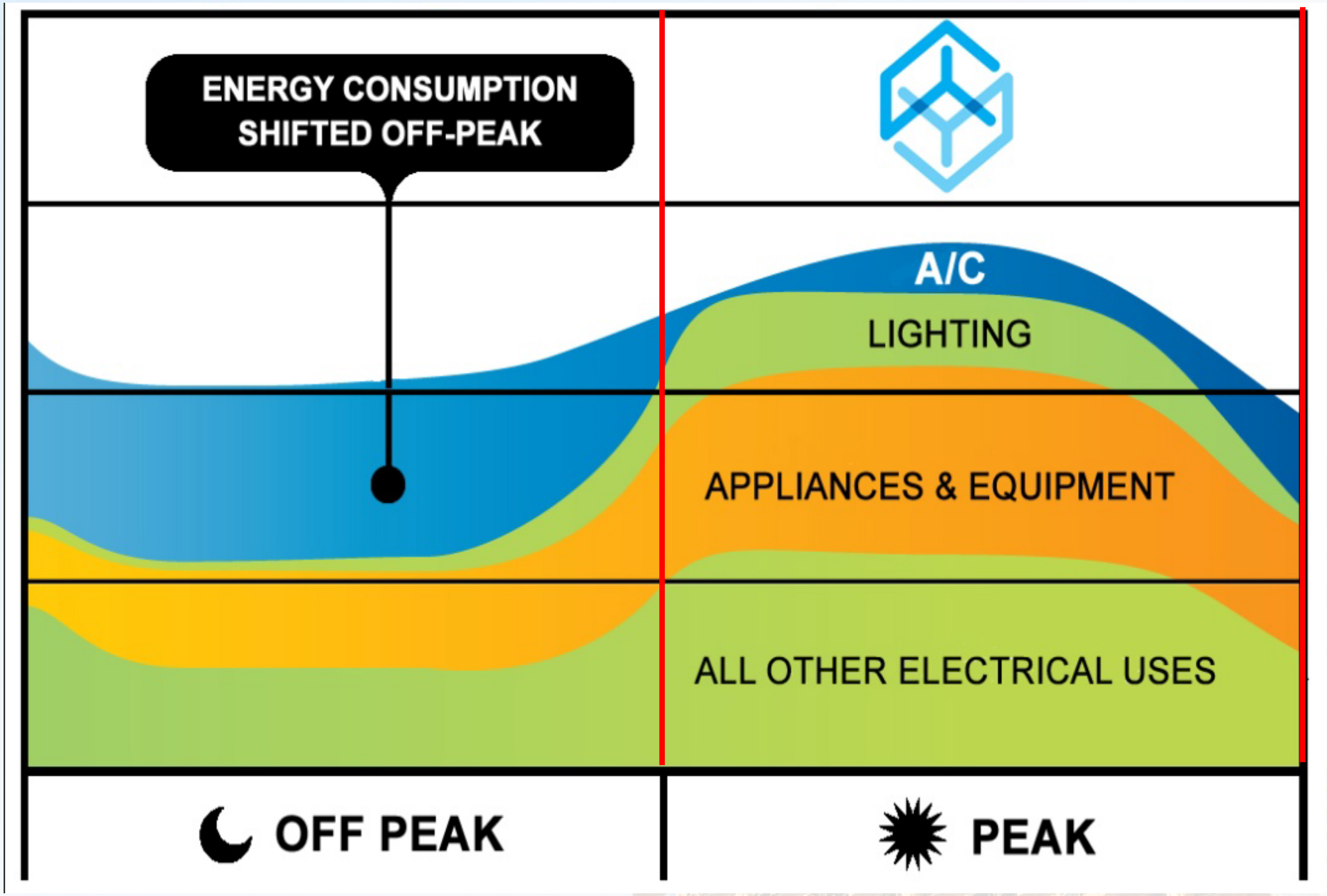
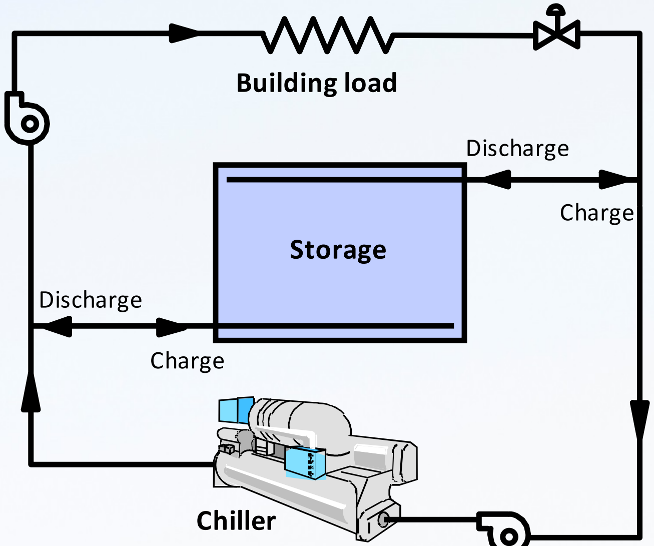
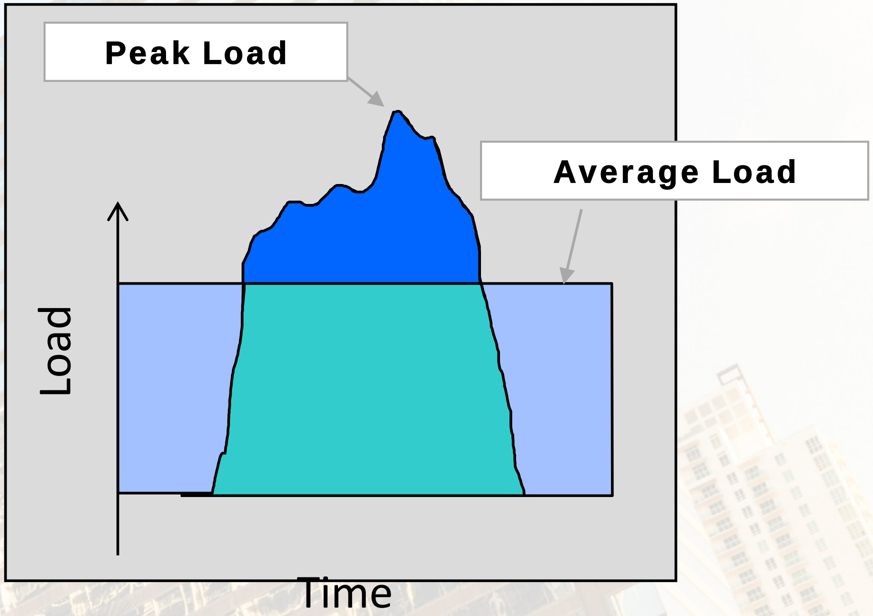
Thermal storage enables shifting chiller operation to off-peak periods



Cool thermal storage concepts

- Decouples energy-intensive cooling generation from building load demands
- Matches total cooling load to chilling capacity over time
- Enables downsizing chillers
- Shifts consumption of electricity from high cost on-peak to low cost off-peak periods





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Recently completed ASHRAE research project found

- Buildings equipped w/TES can enable increased renewable energy utilization ranging from 10%-50% vs. buildings without TES
- Improvements are consistent across geographic regions and building types
- TES is a cost-effective, mature, and readily available today
- Obviously, TES cannot store electrical energy

Source: "Design and Utilization of Thermal Energy Storage to Increase the Ability of Power Systems to Support Renewable Energy Resources, van Asselt, Reindl, and Nellis, ASHRAE RP-1607, 2017.

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TES at 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

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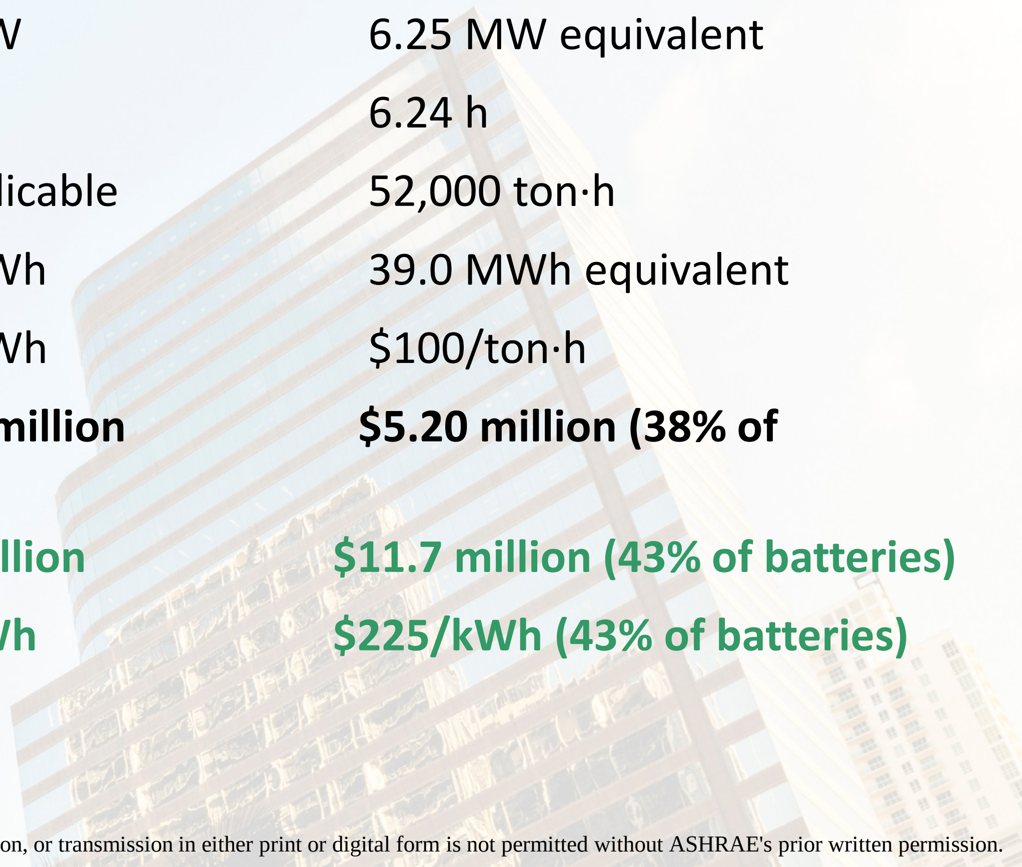
Example: 39 MWh at UNL



	Lithium-Ion Advanced Batteries (hypothetical)	Chilled Water (CHW) Thermal Energy Storage (TES) (actual, 2017-18)
Storage Element		
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

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Energy storage: TES vs batteries

Characteristic	TES	Battery
Capital cost ($/kW, $/MWh)	Low	Moderately high
Roundtrip efficiency	99-133%[1]	75-85%[2]
Life expectancy	30+ years	4.9-7.0 yr[3] (to 70% of nameplate)
Performance degradation over time	Negligible	Significant
Life-cycle cost	Very low	Very high
Material constraints	No	Yes (mining/refining) Li is diffuse material, Co is rare earth
Environmental impact	Very low	High
Flexibility	Thermal-only	Electricity

[1] "Energy and emissions analysis of ice thermal energy storage in the western US ", Sephri & Nelson, *Energy and* Buildings, (202), 2019.

[2] "How three battery types work in grid-scale energy storage systems", McKay, *Windpower Engineering & Development*, March, 2019.

[3] "Life Prediction Model for Grid-Connected Li-ion Battery Energy Storage System", Smith et al., Conf Paper, NREL/CP-5400-67102 ,August 2017.

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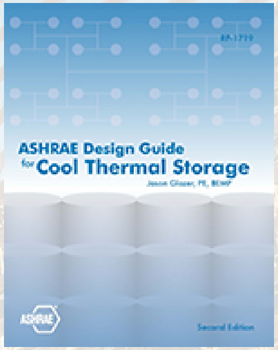
Conclusions

- Big challenges lie ahead
- Thermal energy storage is
  - A strategic technology to enable greater renewable energy production
  - The most capital-cost effective and reliable storage technology we have
- Tap into ASHRAE’s resources to learn more
  - Thermal Storage Design Guide
  - Thermal Storage Short Course



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Questions?

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Backup slides

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Comparative storage costs

Technology	Capital cost ($/kWh)
Li-ion battery	470[1]
Lead-acid battery	549[1]
Flow battery	858[1]
Cool thermal storage	225
Flywheel	600 (est)
Compressed air	500 (est)

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[1] ”Energy storage Technology cost and performance characterization”, Mongird, et al., PNNL Report 28866, July 2019. Some updated information can be found in “2020 Grid Energy Storage Technology Cost and Performance Assessment”, Mongird et al., DOE Report DOE/PA-0204 December 2020.

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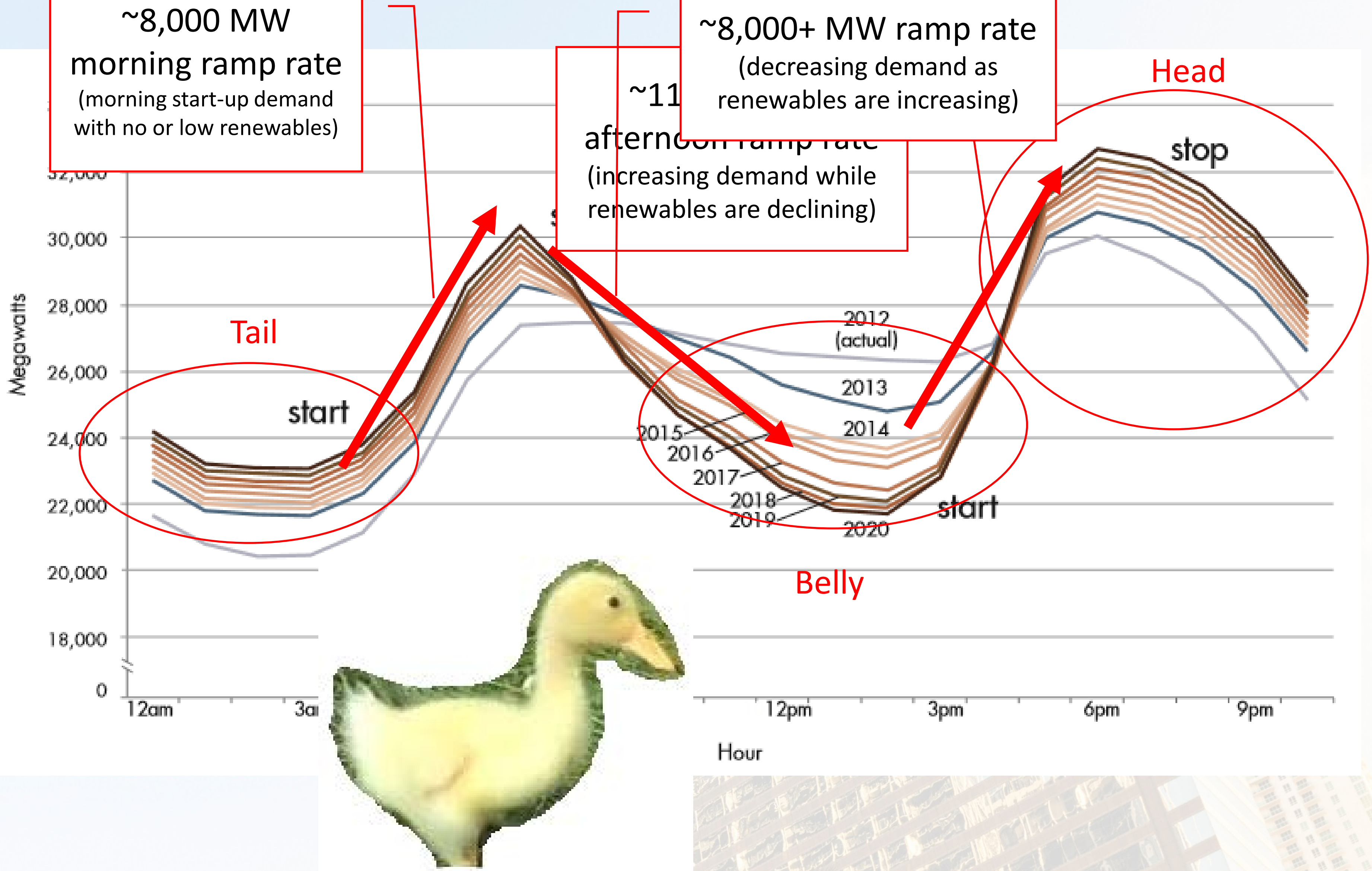
The “duck” curve



~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)

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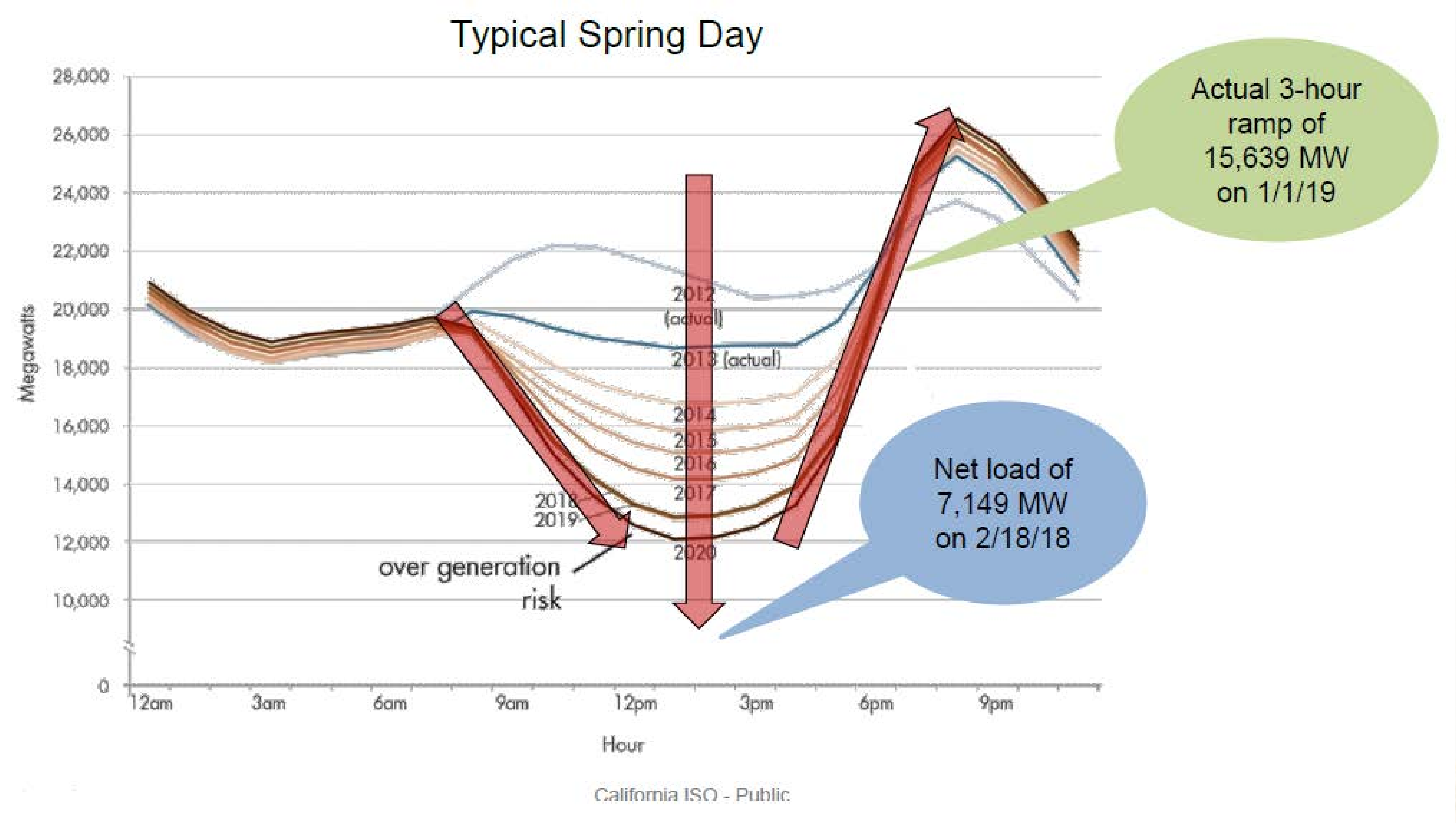
Updated data shows ramp rates and overgeneration worsening



Actual 3-hour ramp of 15,639 MW on 1/1/19

Net load of 7,149 MW on 2/18/18

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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

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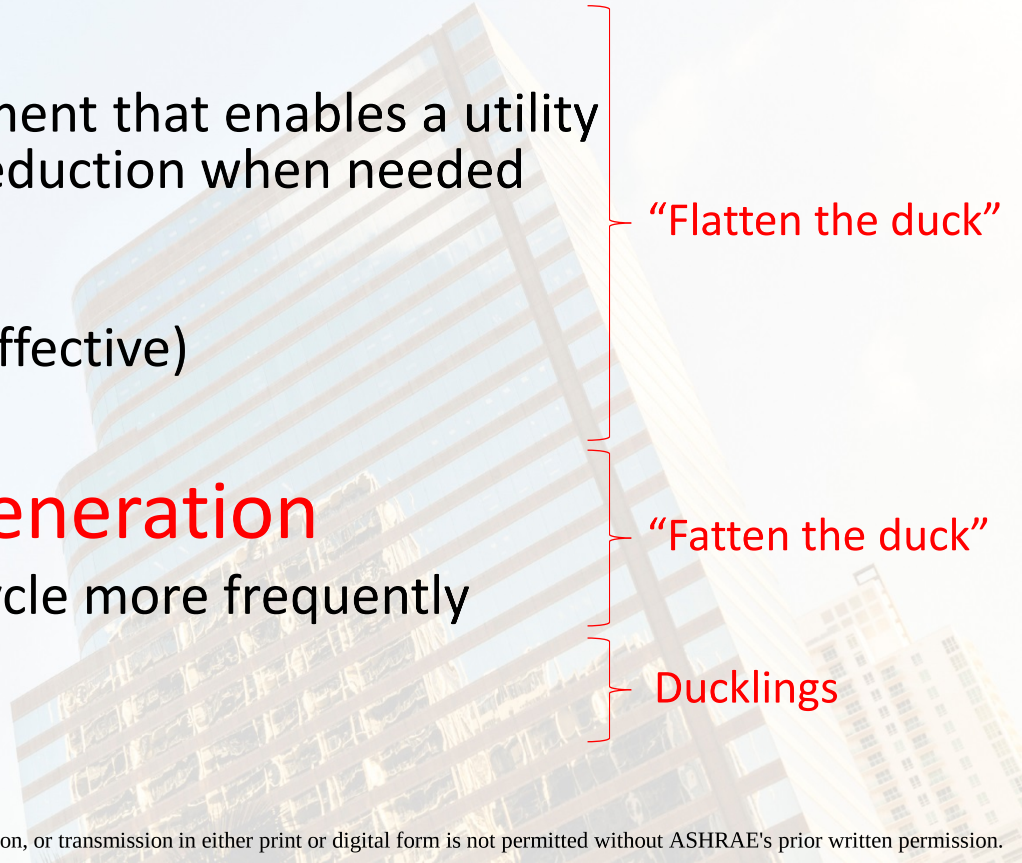
Strategies to cope



- 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

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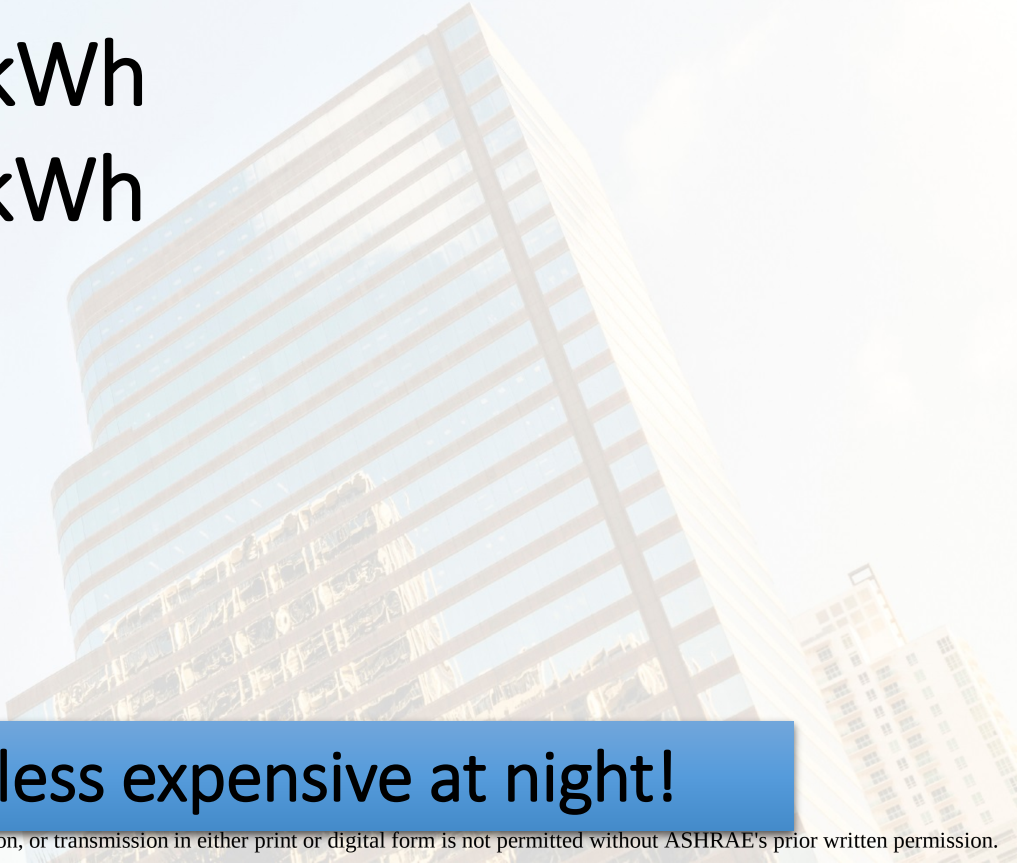
Utilities typically use electric rates to cope



Energy costs:

Day: $0.140/kWh
Night: $0.054/kWh

Electricity is 62% less expensive at night!

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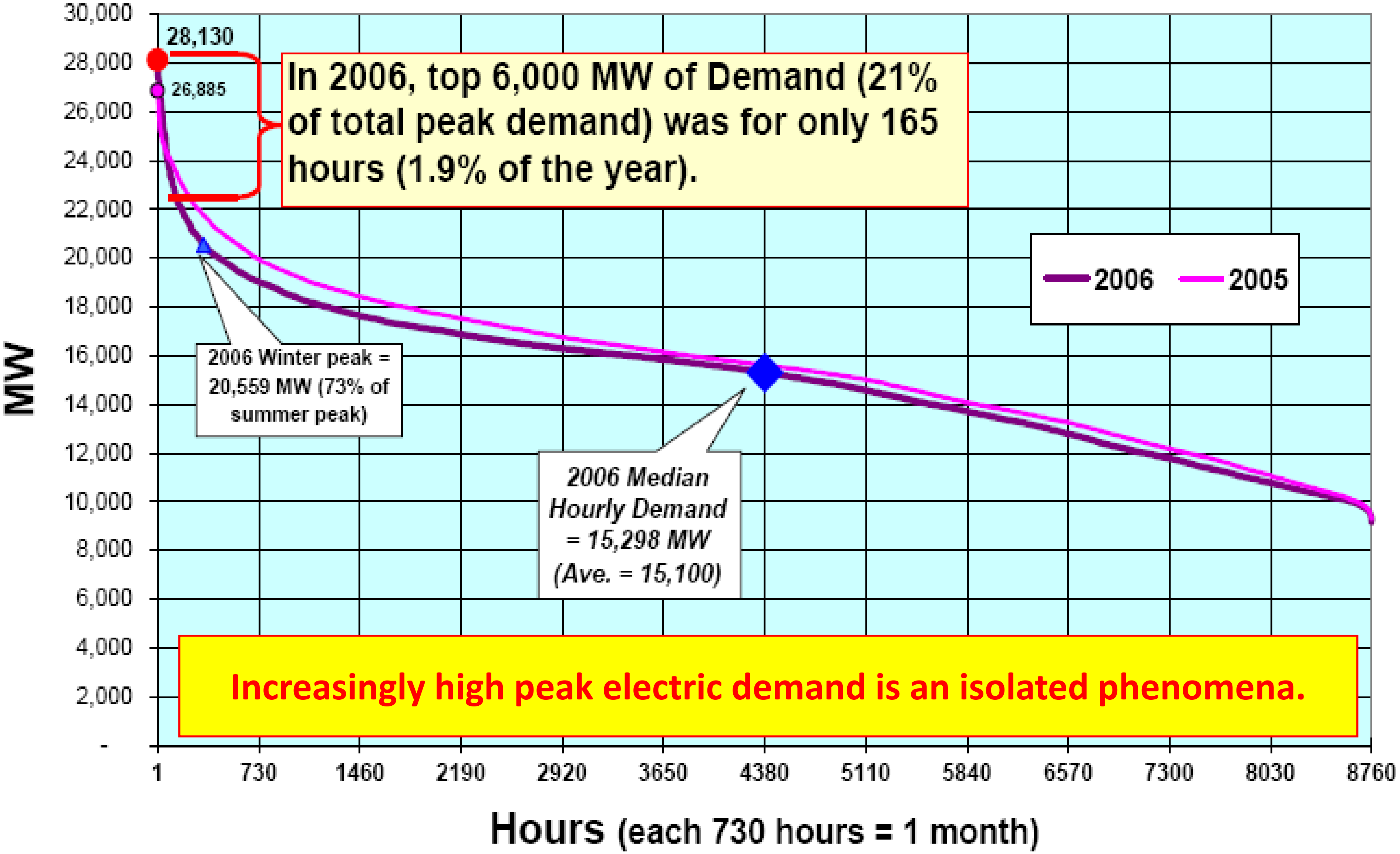
ISO-New England 2005 & 2006 Hourly MW Load Duration Curve



In 2006, top 6,000 MW of Demand (21% of total peak demand) was for only 165 hours (1.9% of the year).

2006 Winter peak = 20,559 MW (73% of summer peak)

2006 Median Hourly Demand = 15,298 MW (Ave. = 15,100)

Increasingly high peak electric demand is an isolated phenomena.

Graph by Clifton Below, NHPUC, from: 2006_smd_hourly.xls and 2005_smd_hourly.xls available at: http://www.iso-ne.com/markets/hstdata/znl_info/hourly/index.html

QUESTIONS?

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