Large Load Management and Grid Planning

Clayton Barrows, National Renewable Energy Laboratory (NREL)

WEIB REP Series

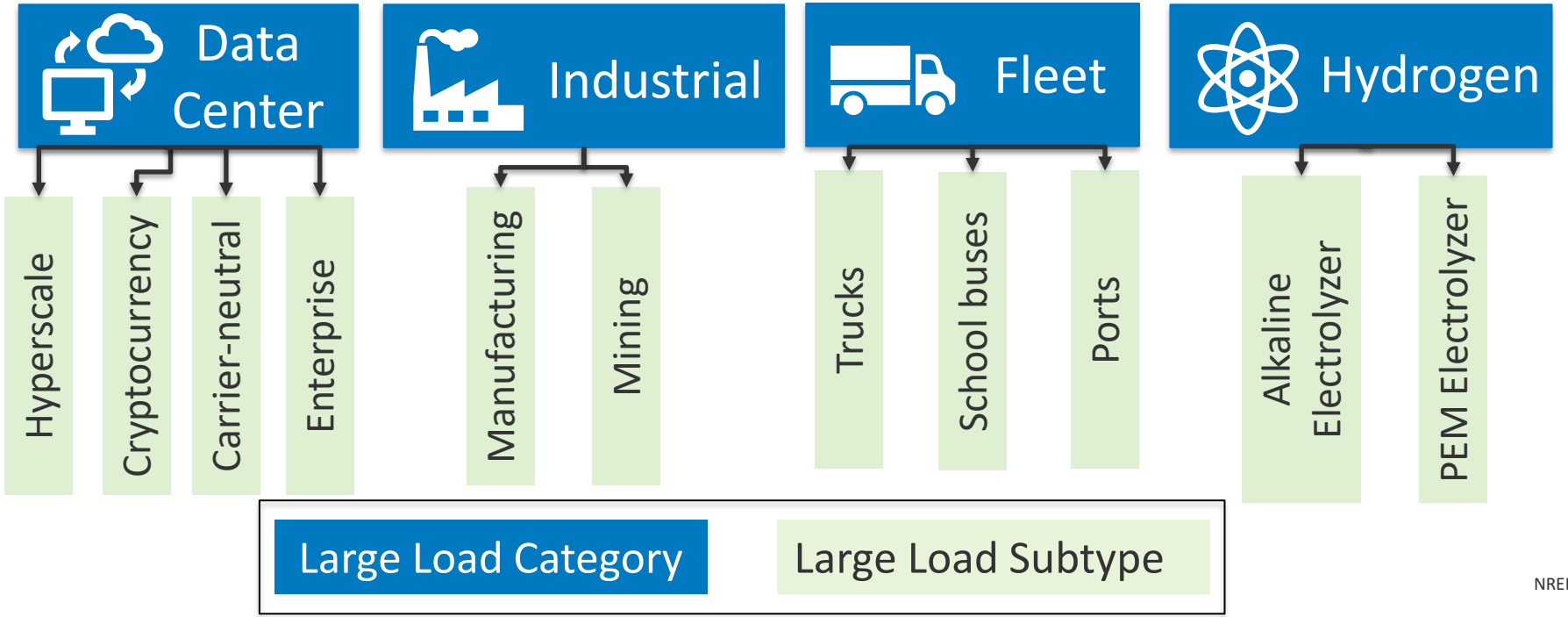
July 31, 2025

Credits: Luke Lavin, Ellie Estreich, Ilya Chernyakhoviskiy, Claire Halloran, Travis Williams, Mike Gleason, Billy Roberts, Andrew Alberg, Patrick Brown, Kelly Yanagihara

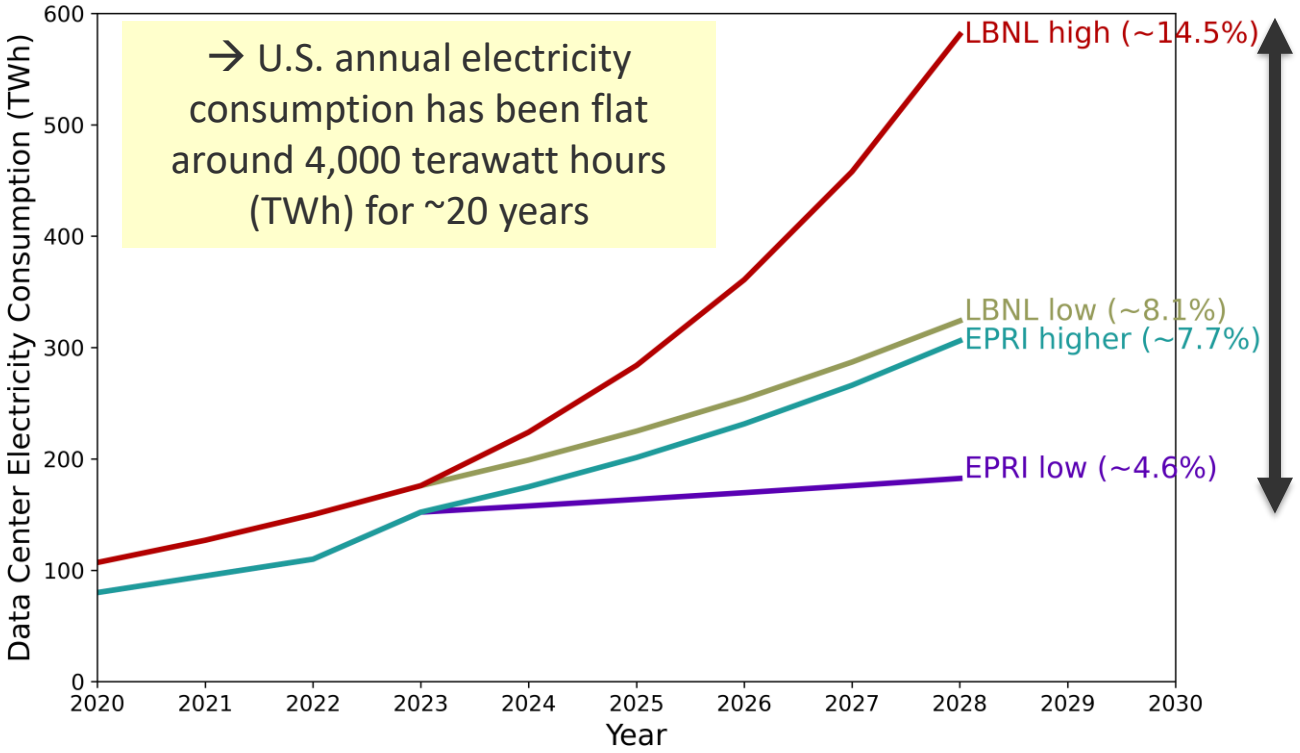
What Is a Large Load?

Categories with non-comprehensive examples

- Common definitions seem to cluster around **50–100+MW**, but many types
- A lot of focus specifically on data centers (including in these slides)



Uncertainty in near-term large load-driven growth

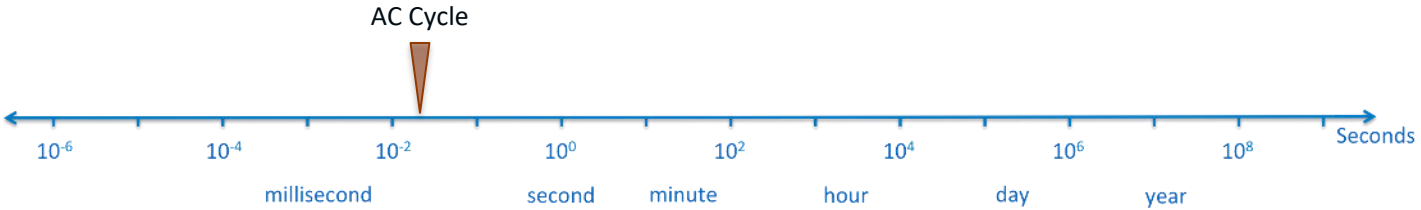


Percents are of 4,000 TWh

Uncertainty in just next few years is 10+% of annual consumption! Even greater beyond 2030

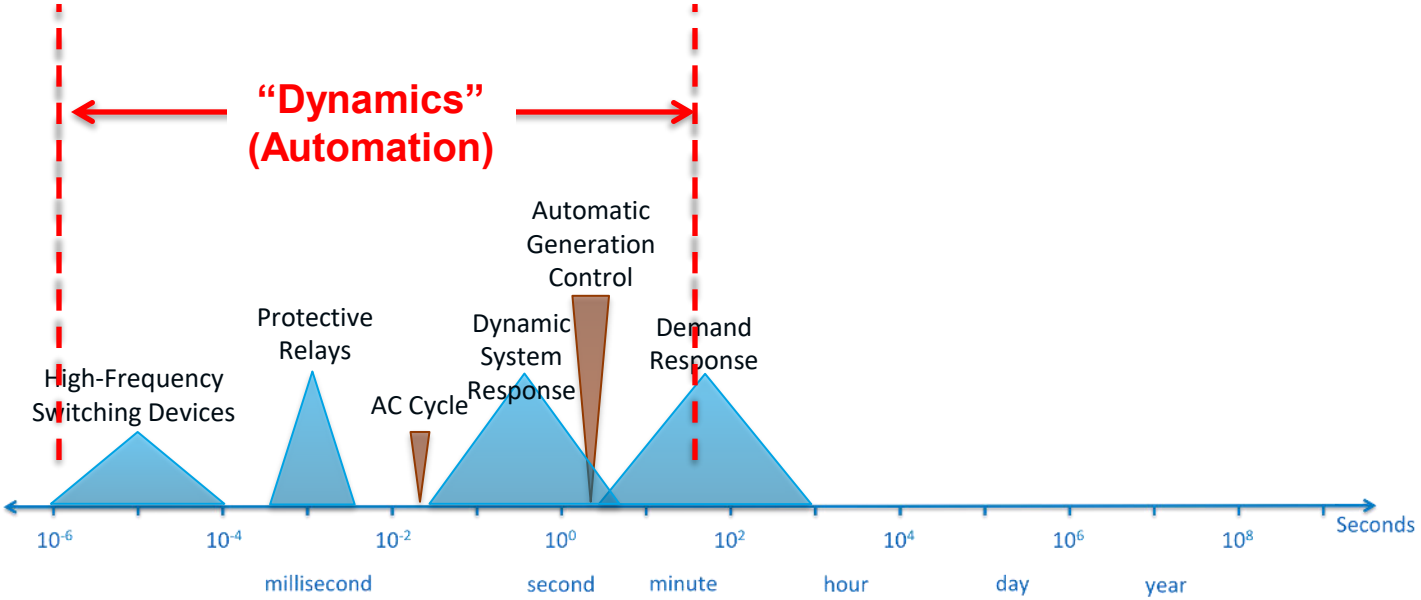
EPRI. "Powering Intelligence: Analyzing Artificial Intelligence and Data Center Energy Consumption." 2024. URL: https://www.epri.com/research/products/000000003002028905.
Shehabi, Arman, Alex Newkirk, Sarah Smith, Alex Hubbard, Nuoa Lei, Md Abu Bakar Siddik, Billie Holecek, Jonathan Koomey, Eric Masanet, and Dale Sartor. 2024. *2024 United States Data Center Energy Usage Report*. Lawrence Berkeley National Laboratory. Report #: LBNL-2001637. http://dx.doi.org/10.71468/P1WC7Q.

Relevant grid decision timescales span 15 orders of magnitude



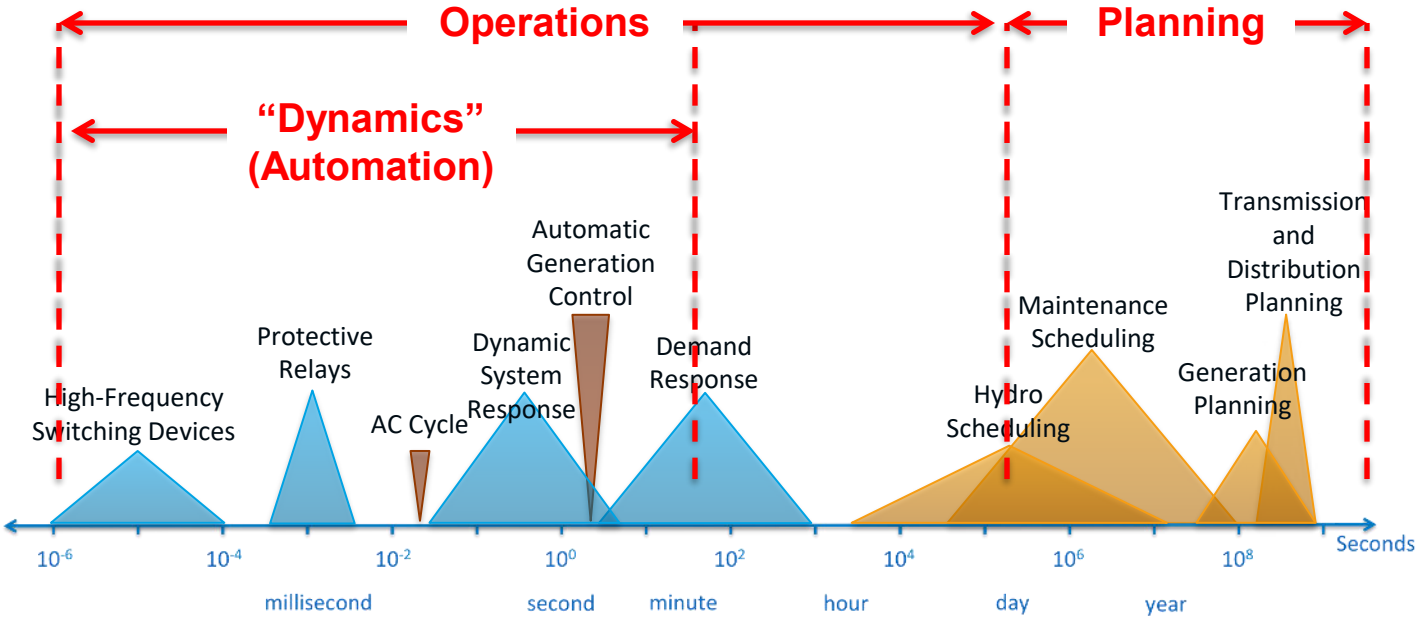
Adapted from A. Von Meier

Relevant grid decision timescales span 15 orders of magnitude



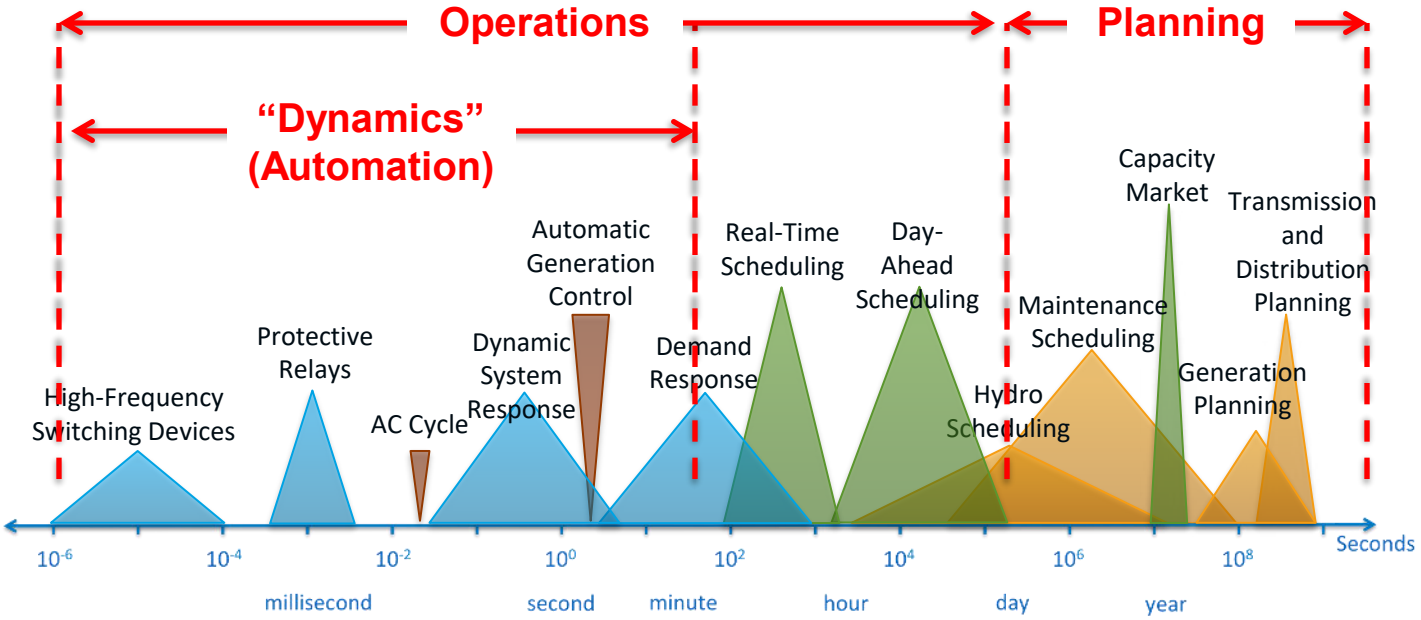
Adapted from A. Von Meier

Relevant grid decision timescales span 15 orders of magnitude



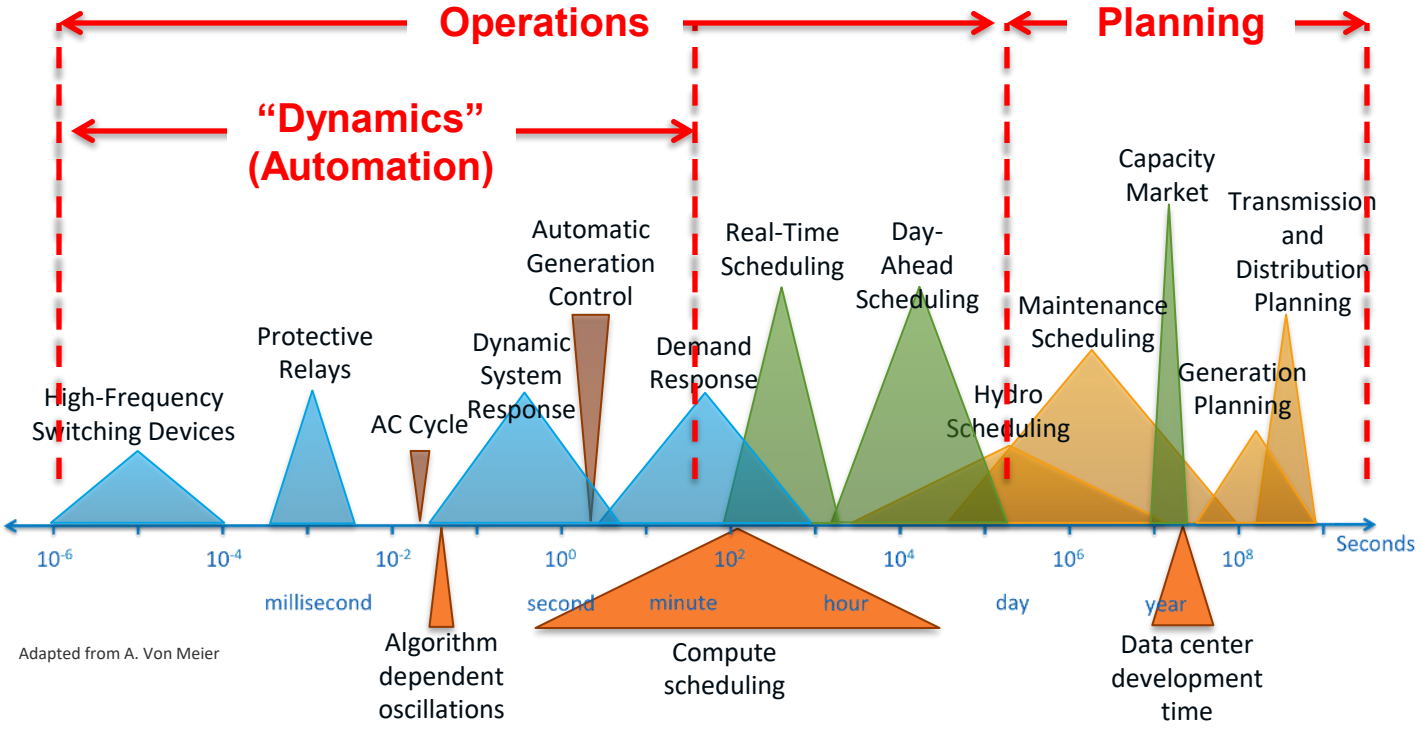
Adapted from A. Von Meier

Relevant grid decision timescales span 15 orders of magnitude



Adapted from A. Von Meier

Relevant grid decision timescales span 15 orders of magnitude



How can data centers operate?

- Data centers are not uniform. What characterizes their differences in electric load?
- Where are the opportunities for impact mitigation?
- Operational data and grid modeling required to understand grid impacts and opportunities.

Image Credit: https://www.deltaww.com/en-us/news/9771

Inform Best-practice Planning through Large Load Siting and Grid Impacts Analysis

Challenge: Where can a capacity-strained grid quickly and flexibly add tens-to-hundreds of gigawatts of new load?

National Scale Resource: Siting feasibility layers identify favorable locations for detailed analysis on clustering multiple large loads for near-term grid integration

Outcome: Open-access siting tools and metrics identify where and how large load clusters can be enabled by policymakers

? **Grid operators**: Maintain reliability

\+ **Utility customers**: Affordable and reliable service

\+ **Industry**: Efficient and fair grid connection

? **States & regulators**: Economic development

Lab impact: Supporting transformational large load and data center growth with objective decision support resources for all stakeholders

Toward a Geospatial Siting Tool

Planning for when and where large loads interconnect to the bulk power system

Data Center Infrastructure in the United States, 2025

About the Map

This map illustrates the geospatial relationships between data center locations, transmission infrastructure, fiber optic networks, and metropolitan areas. The datasets on this map are not produced or curated by NREL. NREL is not responsible for the accuracy, completeness, or reliability of the datasets.

This work was authored by the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE), operated under Contract No. DE-AC36-08GO28308. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.

Transmission Lines

voltage class (kV)

- ≥735
- 500
- 345
- 230
- 161
- 100–161
- <100

Fiber Optic Lines

capacity unavailable

- approximate line route

Data Centers

demand capacity (MW)

- 2,400
- 1,000
- 500
- 100

operating status

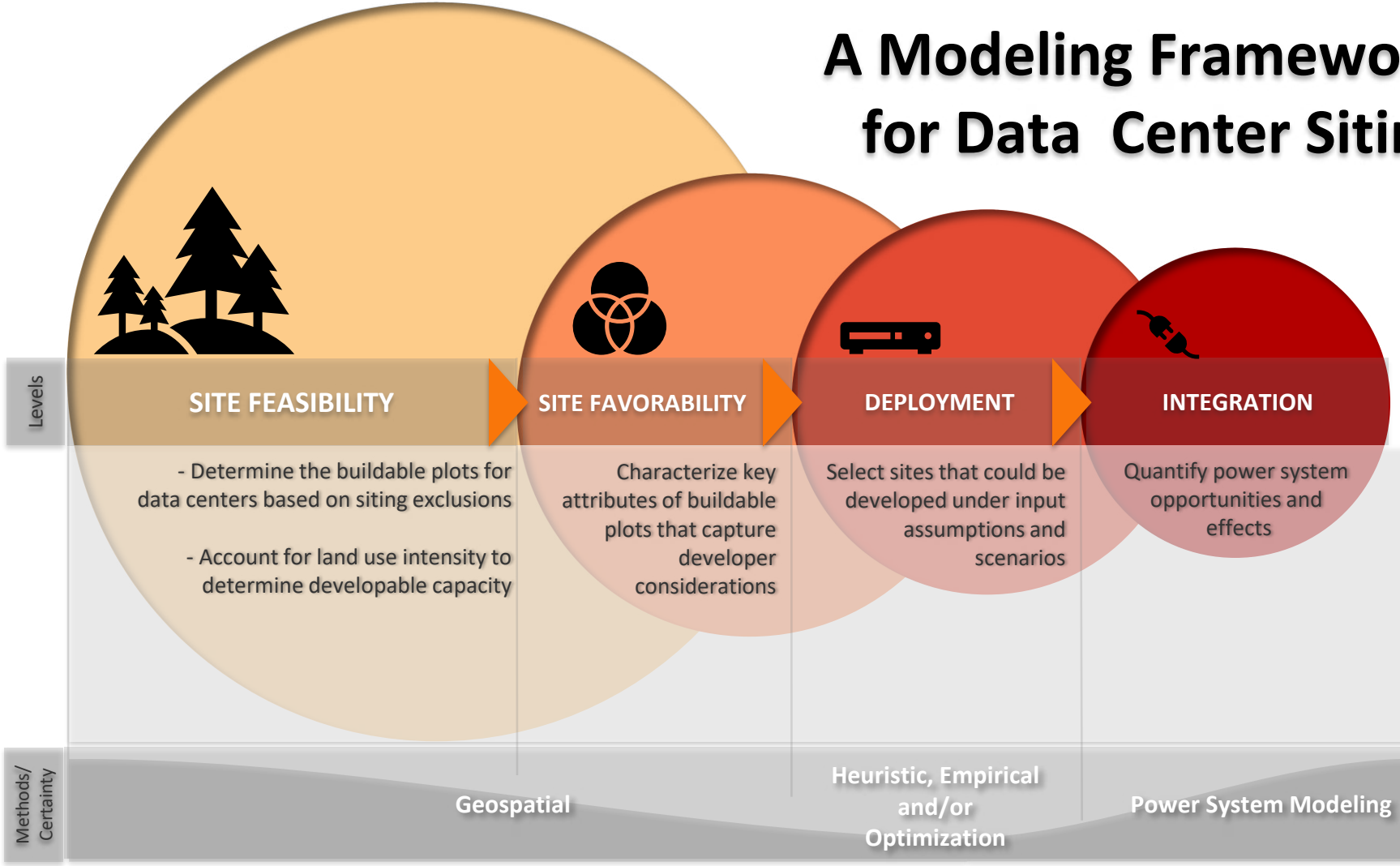
- Operating
- Under Construction

Data Sources

Transmission network and data center information © 2025 Hitachi Energy. Velocity Suite. Fiber optic lines acquired from the International Telecommunication Union from a generalized global coverage dataset.

May 2025 NREL/OT-6A20-94502
Cartography by Billy J. Roberts
National Renewable Energy Laboratory
Golden, Colorado

A Modeling Framework for Data Center Siting



Siting impact mitigation options

Need to understand what it can do before you know where to put it.

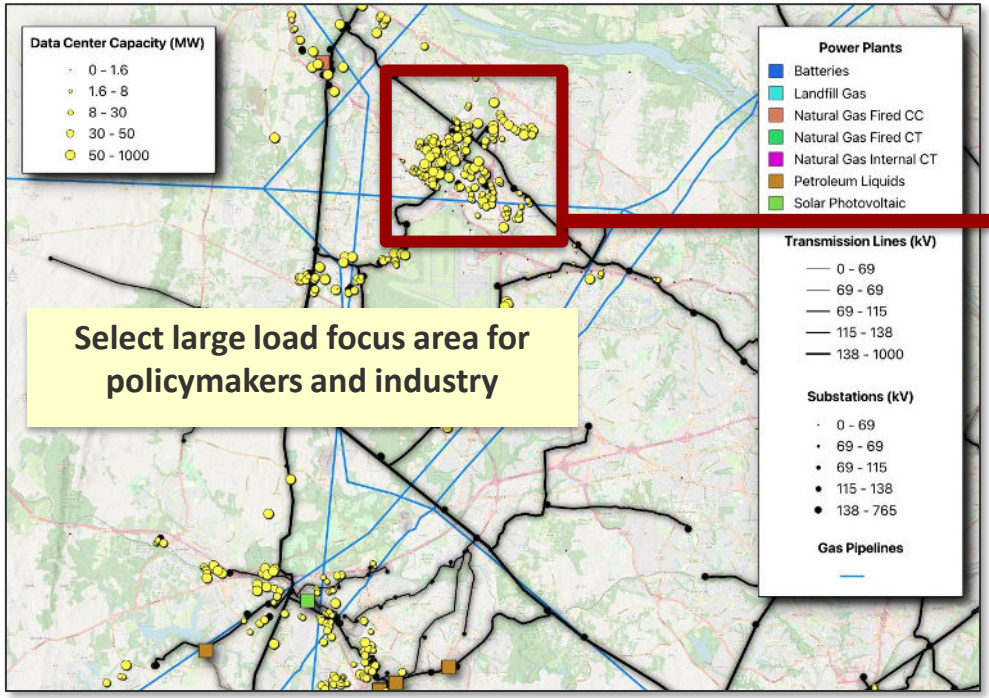
Understanding mitigation options

	Grid Scale Clean Energy Deployment	Grid Infrastructure Enhancement and Expansion	Energy Efficiency and Demand Side Flexibility	Maximizing Data Center Efficiency and Operational Flexibility
				
Example technology solutions *(not exhaustive)*	**Expand existing supply** *(including repurposing existing infrastructure)* • *Solar* • *Onshore wind* • *Storage (batteries)* • *Hydropower* • *Conventional geothermal (hydrothermal)* • *Nuclear (including uprates and relicensing)* • *Offshore wind* • …	**Enhance existing transmission and distribution** • *Advanced reconductoring* • *Grid-enhancing technologies* • *Distribution automation* • *Point-to-point HVDC* • *Advanced flexible transformers* • …	**Improve energy efficiency** • *Building efficiency* • *Geothermal heating and cooling* • …	**Improve data center efficiency** • *Hardware efficiency* • *AI algorithm efficiency* • *Building automation* • *Building efficiency* • *Geothermal heating and cooling* • …
	Scale emerging solutions • *Advanced nuclear* • *Next-gen geothermal* • *Long duration energy storage (LDES)* • *Carbon capture storage (CCS) on power plants* • *Clean hydrogen* • *Concentrated solar power* • …	**Expand transmission and distribution** • *Advanced conductors* • *Interregional and regional high voltage DC / AC transmission* • *Distribution system* • …	**Manage and flex demand** • *Virtual power plants* • *Distributed energy resources* • *Microgrids* • *Fuel cells* • …	**Enhance operational flexibility and efficiency** • *Flexible operational processes* • *On-site power generation and facility design optimization* • …
Example enablers *(not exhaustive)*	**Advance key enablers** • *Proactive planning* • *Evolving regulatory decision-making and processes* • *Grid market frameworks that fully value energy solutions* • *Modernizing interconnection processes* • *Permitting enhancements* • *Innovative tariff structures* • *New financing structures (such as advanced market commitments)* • *Supply chain and workforce development* • …			

Toward a Framework for Efficient Large Load Grid Planning

Where we are going with forward-looking planned work

Long-term Vision Enables Site-specific Analysis to Aid Policymakers



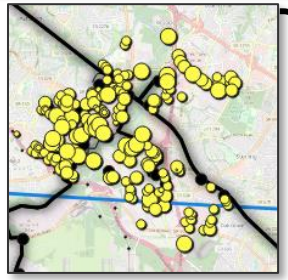
Pictured: Northern Virginia is the current global data center capacity hub

Question Answered: Considering siting constraints, what are best near-term options?

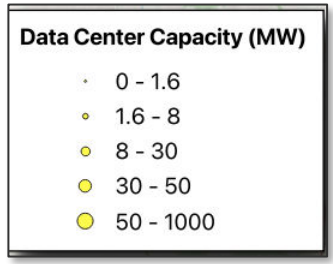
Demand Flexibility

Electricity Storage

Transmission Upgrades



Sienna



Thank you!

www.nrel.gov

Contact: Clayton.Barrows@nrel.gov

NREL/PR-6A40-95736

This work was authored by the National Renewable Energy Laboratory for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy's Office of Policy and U.S. Department of Energy Office of Energy Efficiency and Renewable Energy's Grid Deployment Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

Photo from iStock-627281636

NREL