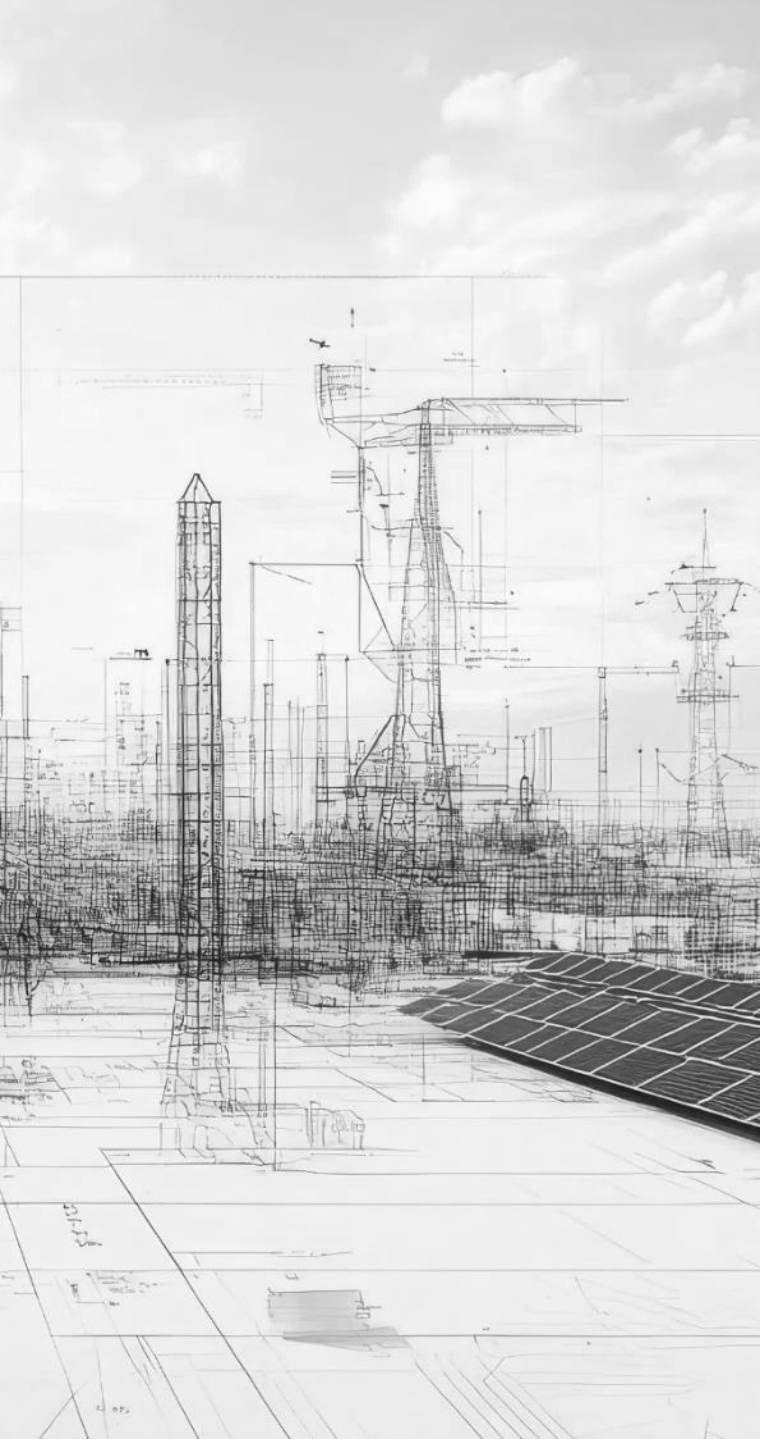

Active MV Substations to Power the Hyperscaler Datacenter Complex

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Advanced Research Projects Agency – Energy (ARPA-E)

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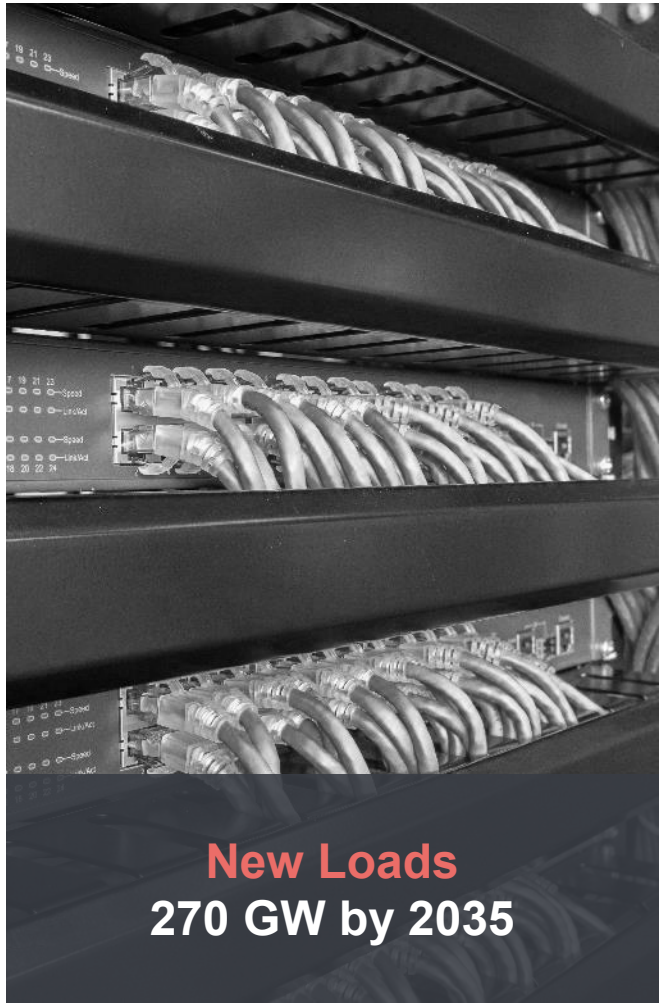
Future Grid and Substations Might Look Very Different!

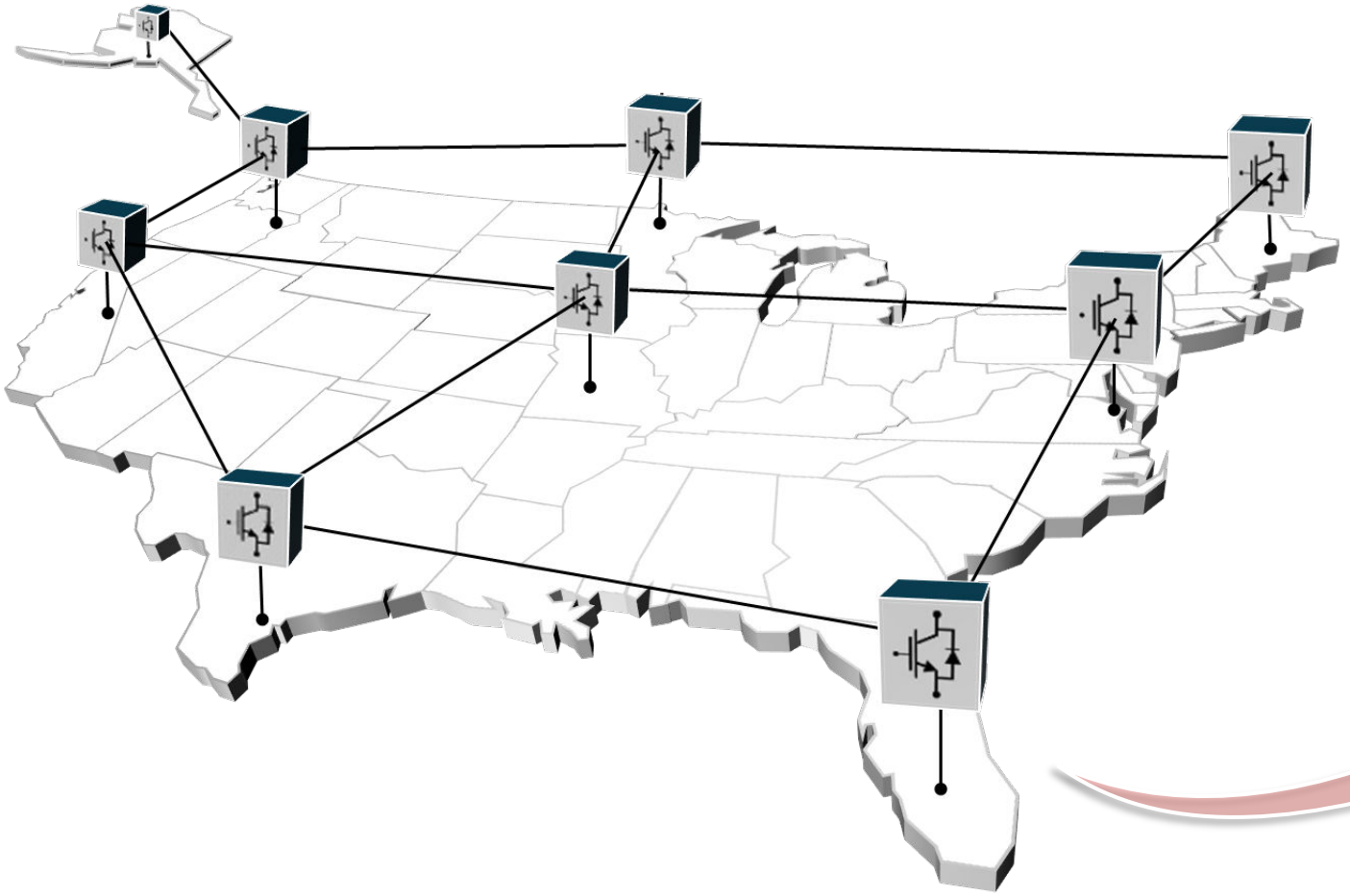
New Sources
2.6 TW in queue



New Loads
270 GW by 2035

Resiliency
$150B/year

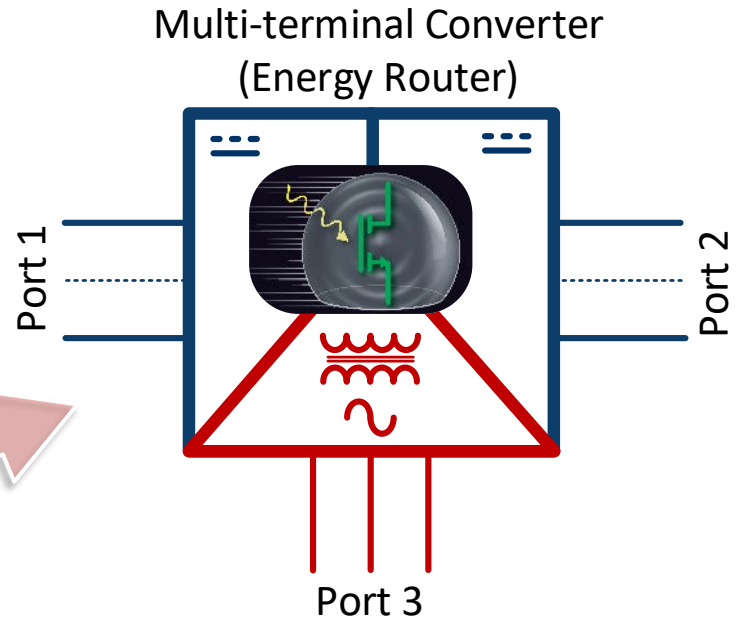
DC-GRIDS



Focus on two technical categories:

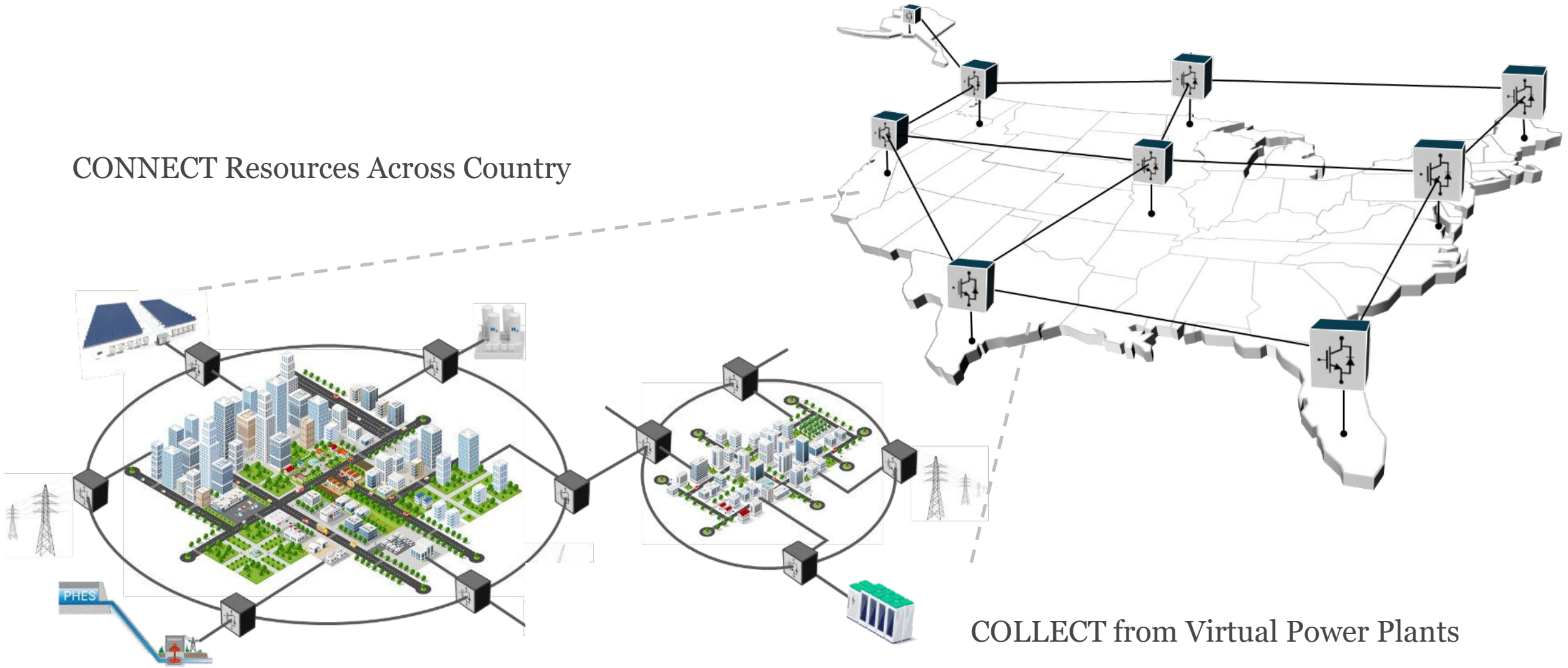
Category A: Novel submodules and modular high-voltage power electronic valves; and

Category B: Technologies that enable highly compact multi-terminal converter stations.



How May the Grid Architecture Evolve and the Role of Substations?

CONNECT Resources Across Country



COLLECT from Virtual Power Plants

Active Substation Technology and Flexible Large Power Transformers (LPT)

Active Substations With Highly Flexible Operation Capability (For HV to MV Substations)

Disrupting Large Power Transformer (LPT) Manufacturing, Substation Commissioning, Supply-chains and Performance with Modular Active Substations.

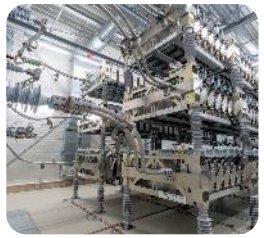
Workshop Objectives for Sub-Tx – MV (110 – 24 kV) class substations:

Flexible Large Power Transforming Substations

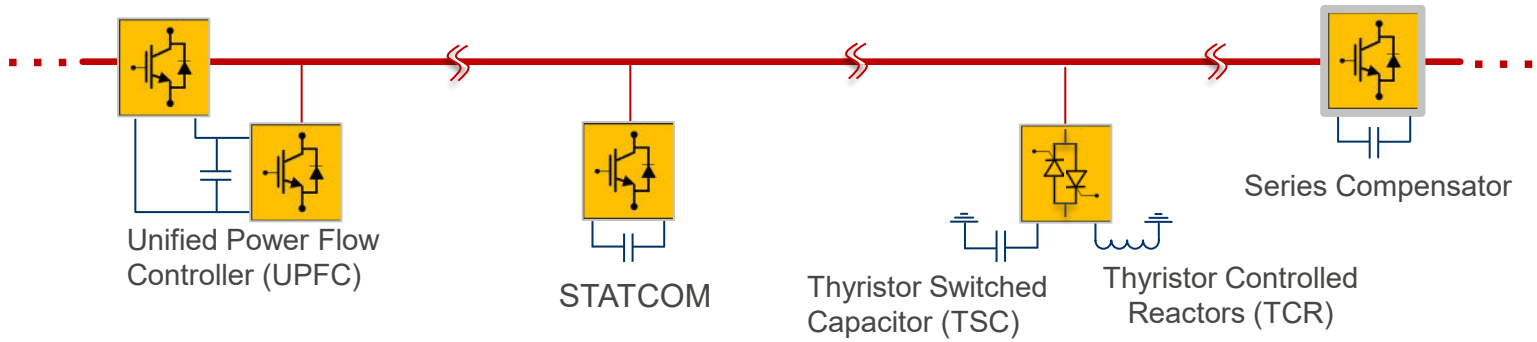
- **Advance Manufacturing of LPTs (> 50 MVA)**
  - Innovative Magnetic and Dielectric materials
  - Improved bushings and advanced E-field management
  - Higher Magnetic Flux materials and thermal design
  - Self-healing and disruptive winding insulation
  - Modular transformer designs
- **Flexible Power Transformers using Modular Power Converters**
  - HV Solid-state Transformers (HF SST) for HV AC&DC applications
  - Hybrid Transformers with integrated Energy Storage
- **Modular LPT designs with Basic Transformer Blocks (BTB)**
  - Mobile Substations for capacity and resiliency management.
  - Reduction in Substation Planning, Design and Commissioning.
  - Large magnetic and copper materials reduction

Portable Substation - 100 MVA, 15-345 kV

Band-Aids for the Existing Grid Substations

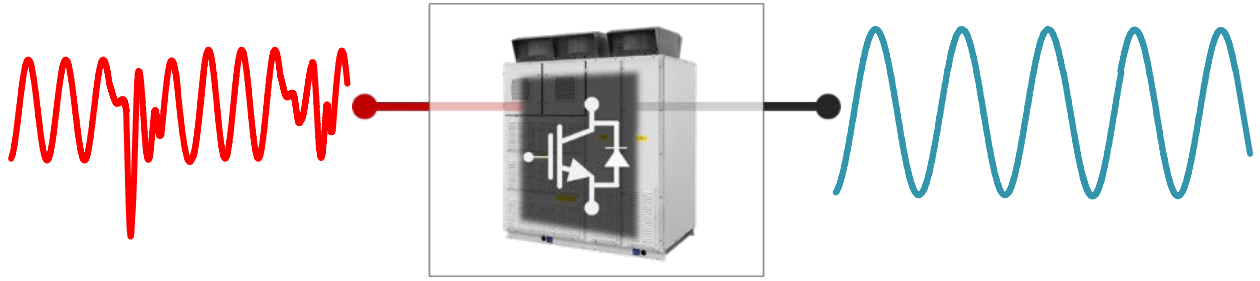


Flexible Alternating Current Transmission System (FACTS)



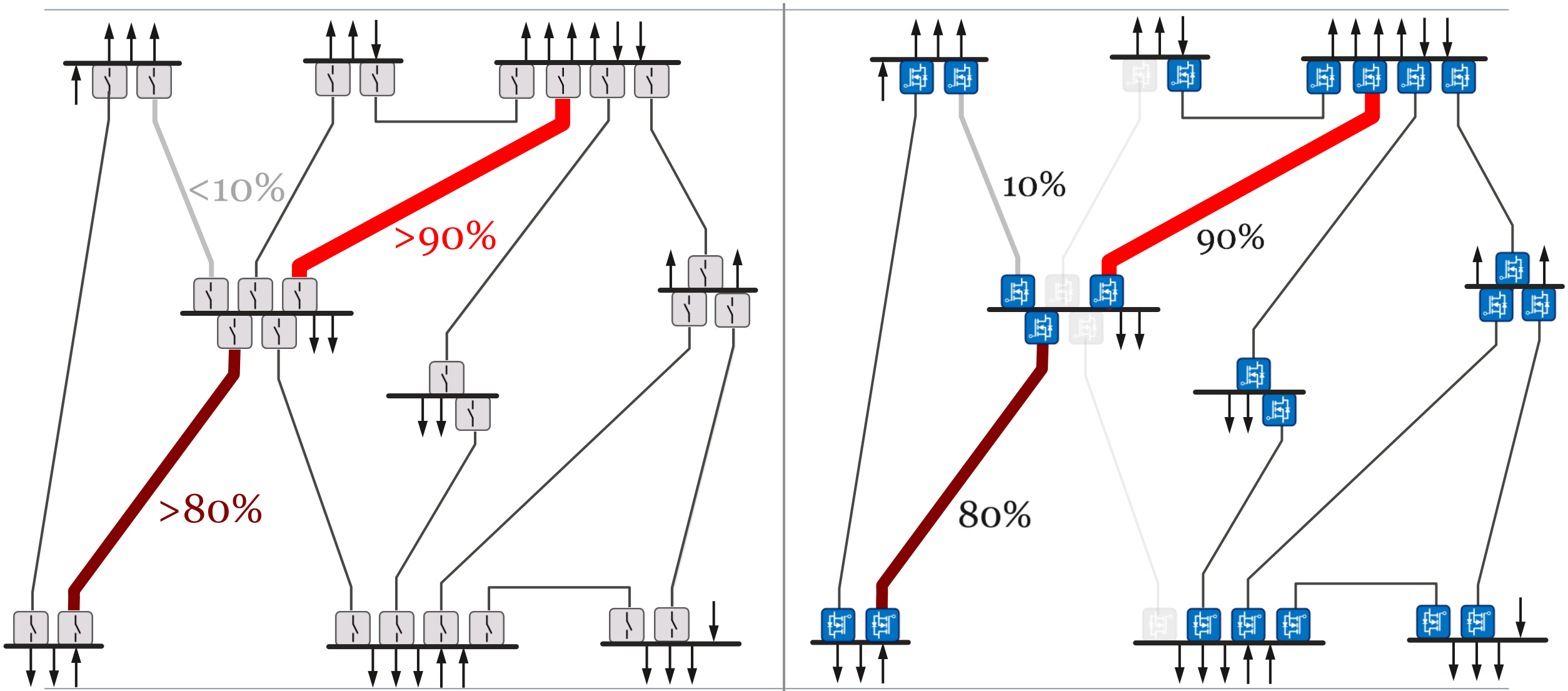
Conventional Transformer

Solid-state Transformer/Substation



- Transformer only features voltage step-up/down functionality, no active filtering, control and protection
- FACTS devices / active filtering needed to improve power quality
- These devices cannot increase the line capacity in the way HVDC can
- Active substations already include most of the FACTS functionality

Conventional VS Active Substations

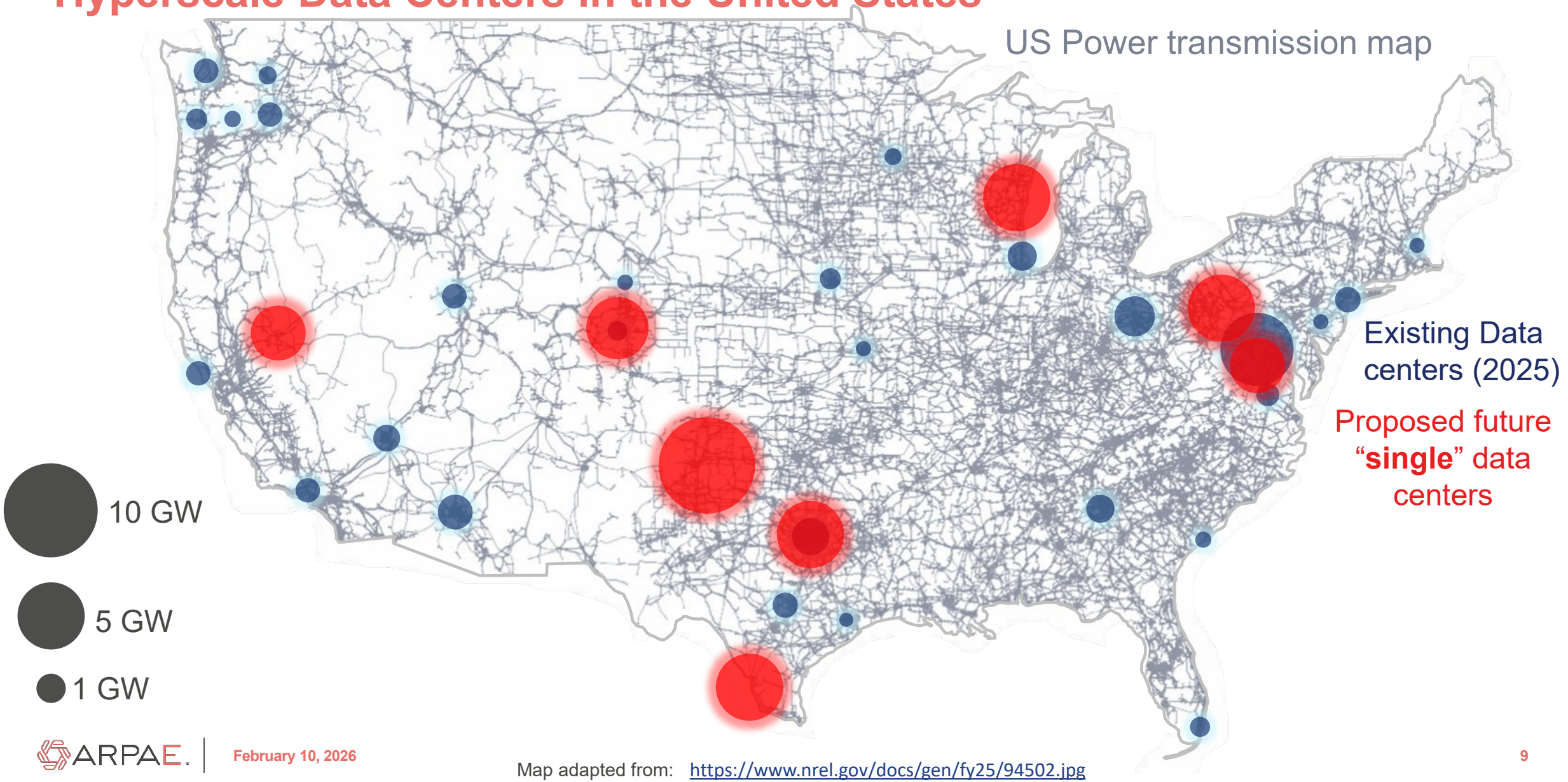


GW Hyperscalers

Data centers have grown up to be exceptionally large power users (>1 GW per complex).

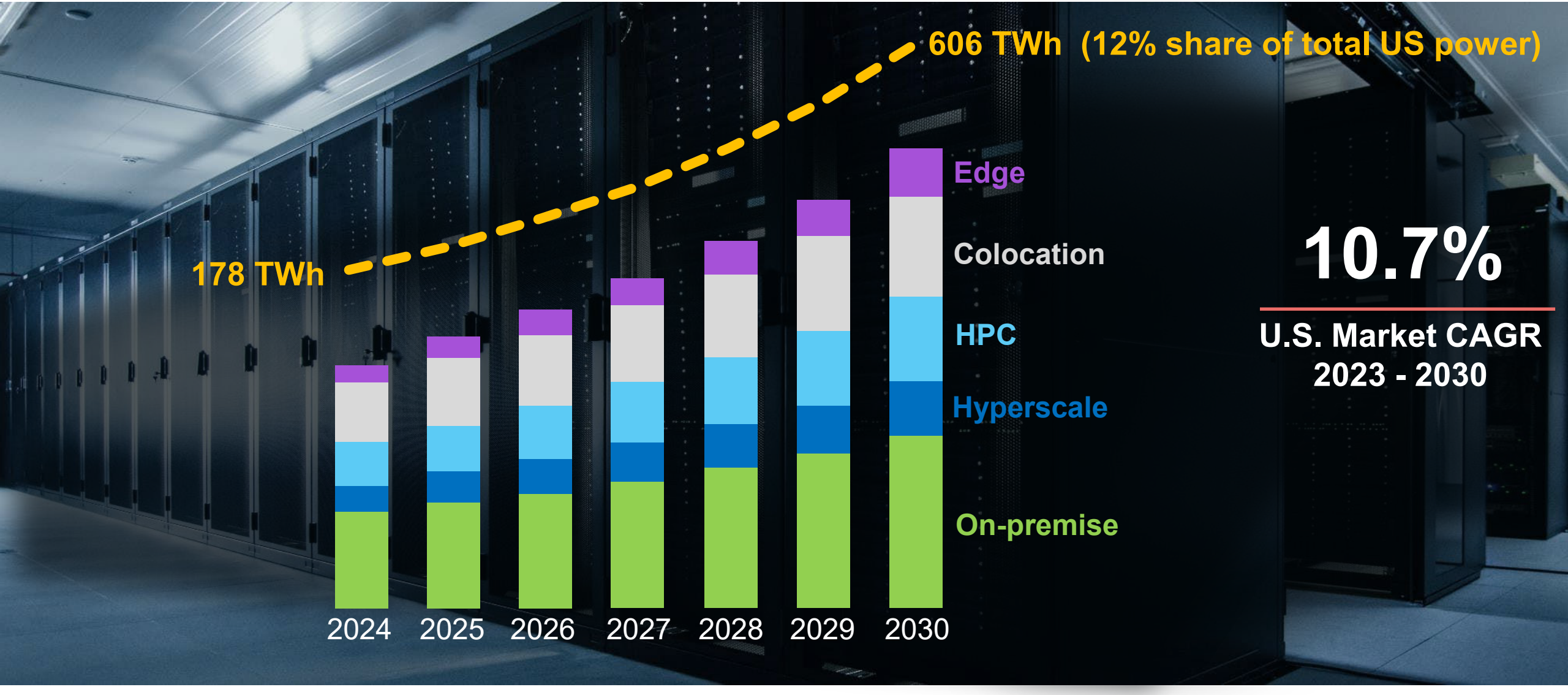
Require city size power supplies at 4-9 nines of reliability

Hyperscale Data Centers in the United States



Map adapted from: https://www.nrel.gov/docs/gen/fy25/94502.jpg

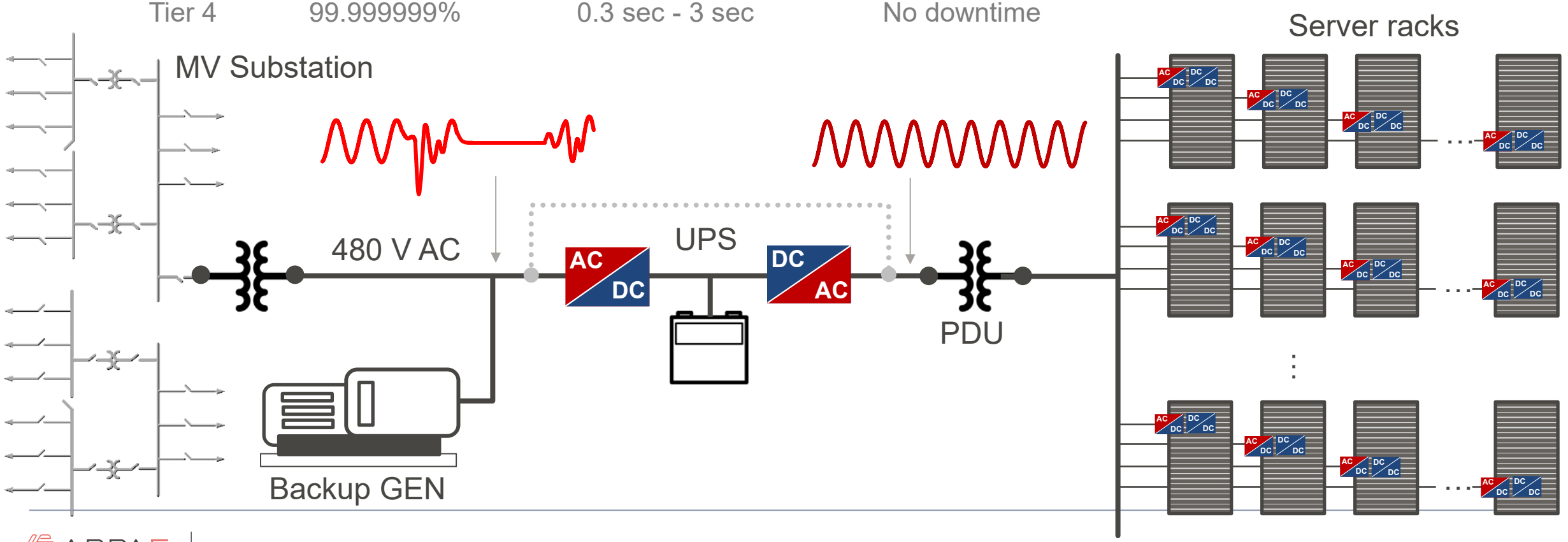
U.S. Data Center Market



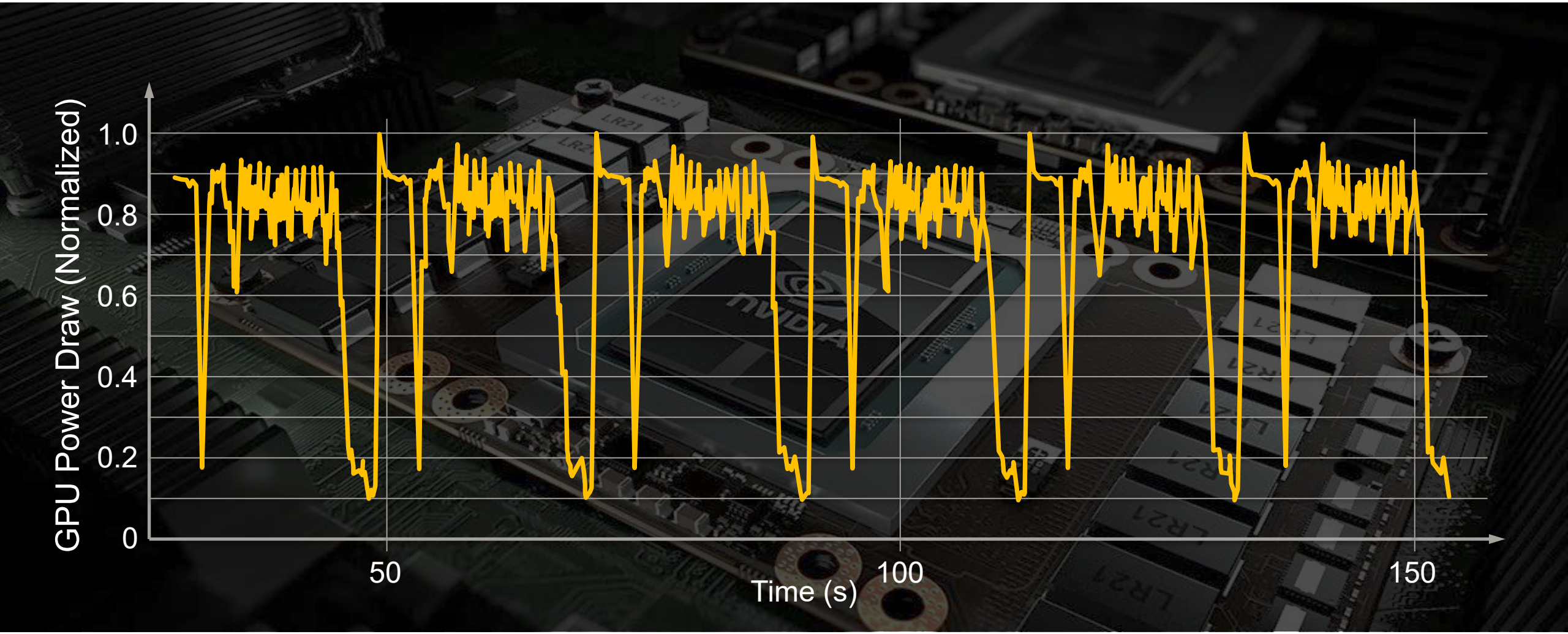
Data from: grandviewresearch.com and VC

Data Center Conventional AC Distribution

Tier Level	9's of Availability	Downtime	User Value
Tier 0	99.9%	8.77 hours	Protect hardware
Tier 1	99.99%	53 minutes	Backup power/ basic site infrastructure
Tier 2	99.999%	31.6 sec - 5.3 min	Preserve data integrity – minor interruption
Tier 3	99.99999%	3 sec – 31.6 sec	Increased uptime – business continuity
Tier 4	99.999999%	0.3 sec - 3 sec	No downtime

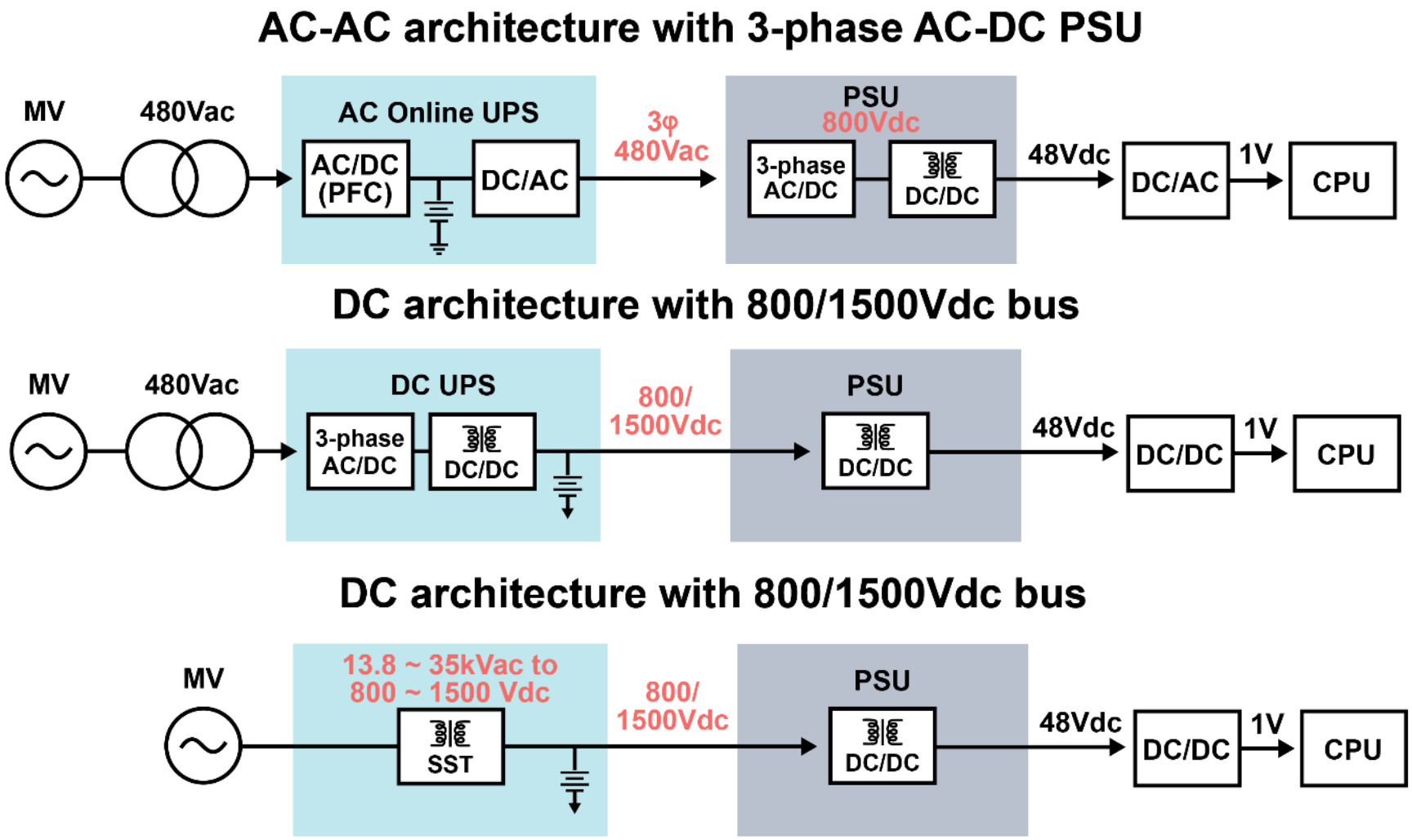


Highly Dynamic Load Profile



AI training load profile is highly dynamic: **0 → 2 MW in 50 ms**

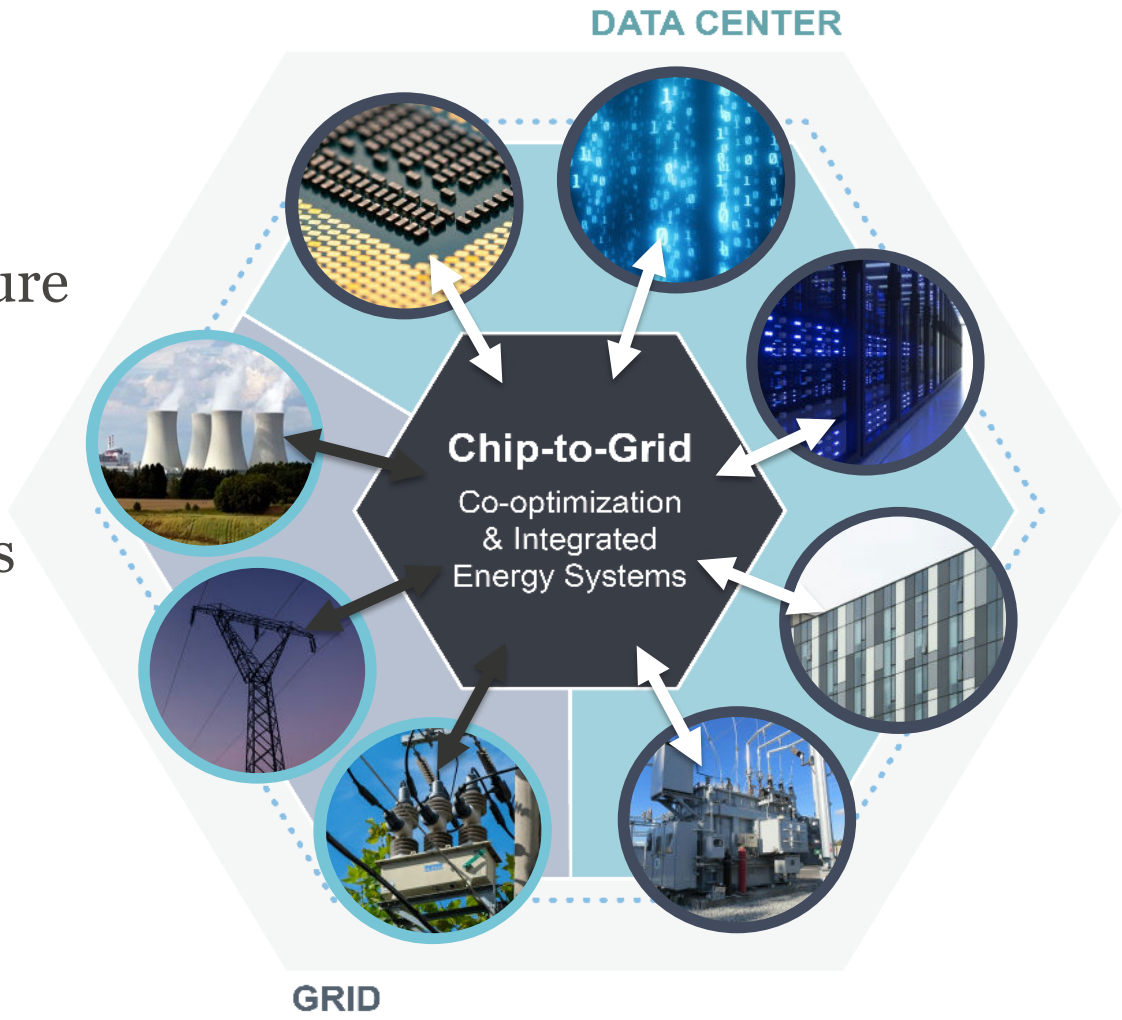
Data Center Power Supply Architectures



Powering Data Centers from Grid to Chip

- >69 kV to 1 V optimization
- Power electronic hardware
- Distributed Energy Storage with DC architecture
- Distributed reliability scheduling

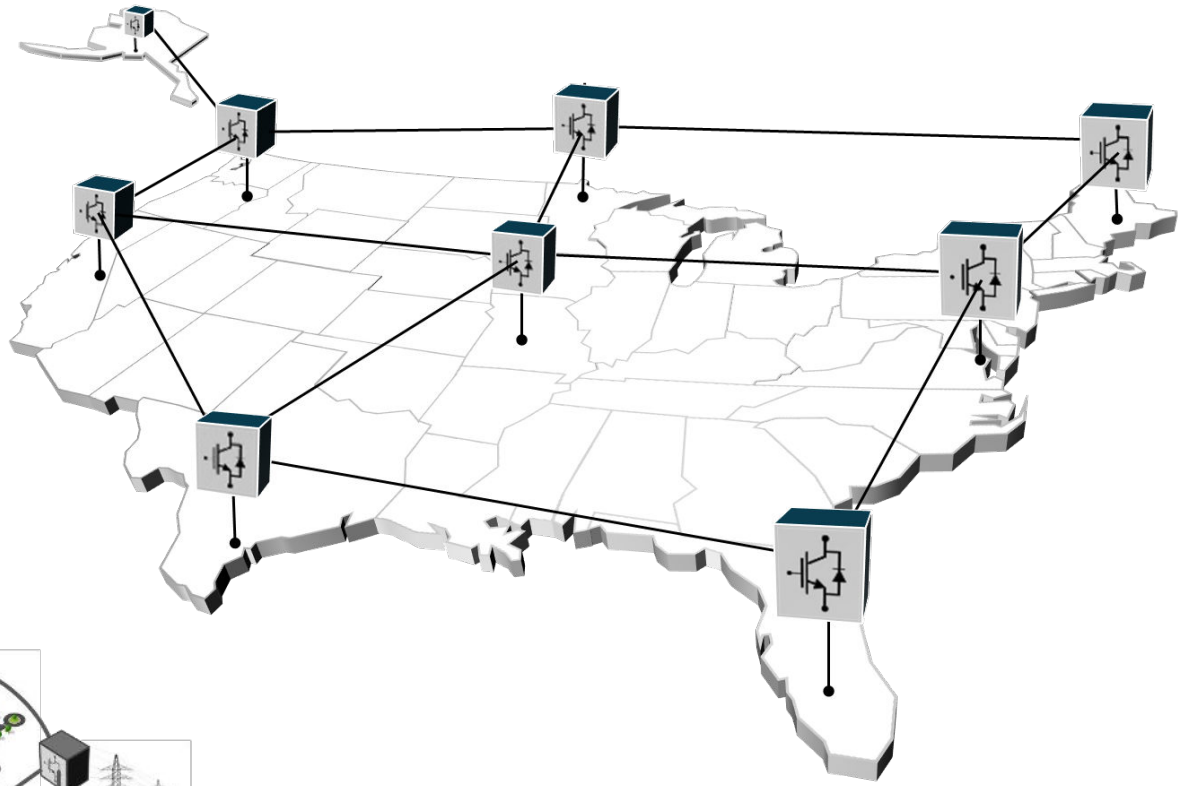
  v/s power supply
- Rapid development with limited grid upgrades
- Reduction in critical materials, Cu & GOES
- Grid System Support and Operation
- Co-generation Integration

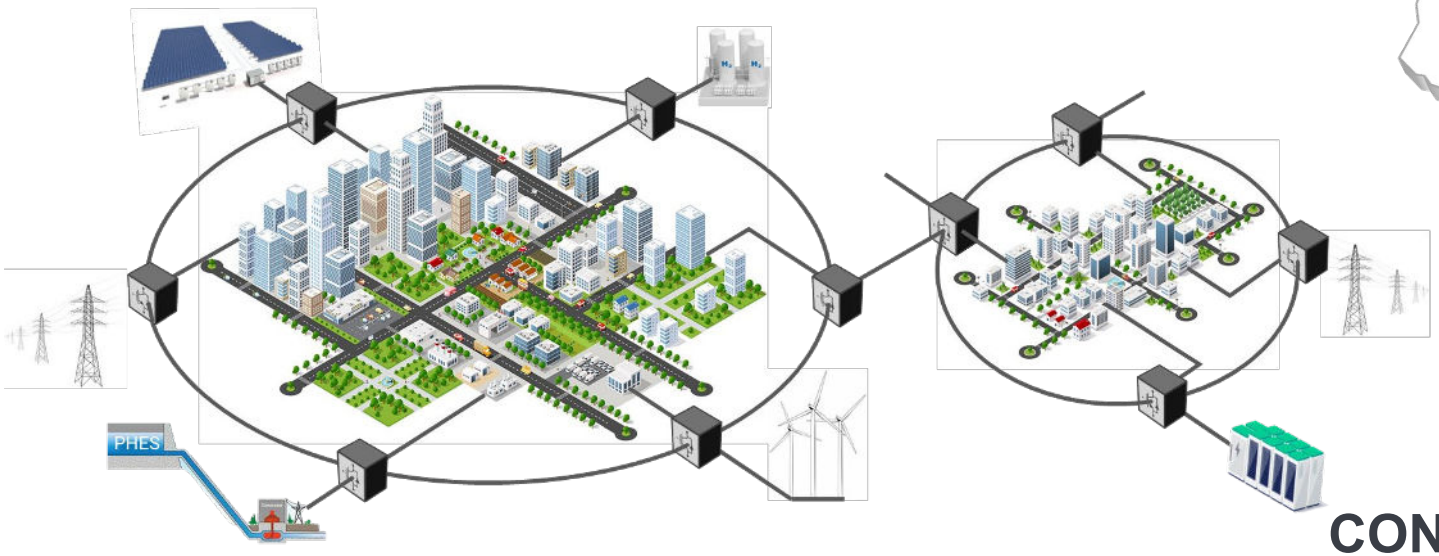


Final Thoughts

- Reduce Traditional LPT Critical Materials - SST
- Fast-track Grid Capacity and Performance
- Increase Load Reliability & Resiliency

  »Fast-track Modular Active Substations





CONNECT Sources and Loads

Thank You!

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