Grid Flexibility Study

Prepared for NEMA

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Contents

Executive Summary

Resurgent electricity consumption growth challenges grid reliability according to NEMA-PA Consulting Grid Flexibility study

- The electroindustry is at the forefront of a nationwide drive to improve the reliability and resilience of the power grid ahead of growing power demand from data centers, e-mobility, building electrification, and manufacturing reshoring
- After two decades of stagnant power demand growth and scant transmission and distribution additions, power gap risks are expected to rise during peak demand events

Reliability risks are rising

- Demand growth is likely to increase twice as rapidly over the next 25 years compared to the last quarter century, with wide variation in growth rates across regions
- Both diurnal and seasonal peak demand periods are shifting unevenly across regions as buildings and mobility are electrified
- Recent generation capacity additions are intermittent and far from urban centers
- Transmission and distribution additions to meet demand growth are 5 to 10 years out

Executive Summary

Grid Enhancing Technologies (GETs) can improve reliability

- Upgrading existing grid infrastructure including
  - Advanced power cables can double power flow capacity
  - Dynamic line rating augments capacity in favorable weather
  - Smartgrid technologies such as digital substations and advanced metering enable effective demand response solutions
- Optimizing power demand by shifting consumption away from peak periods
- Storing energy produced by intermittent generation sources
- Upgrading building equipment/systems for energy efficiency
- Adding behind-the-meter generation and microgrids

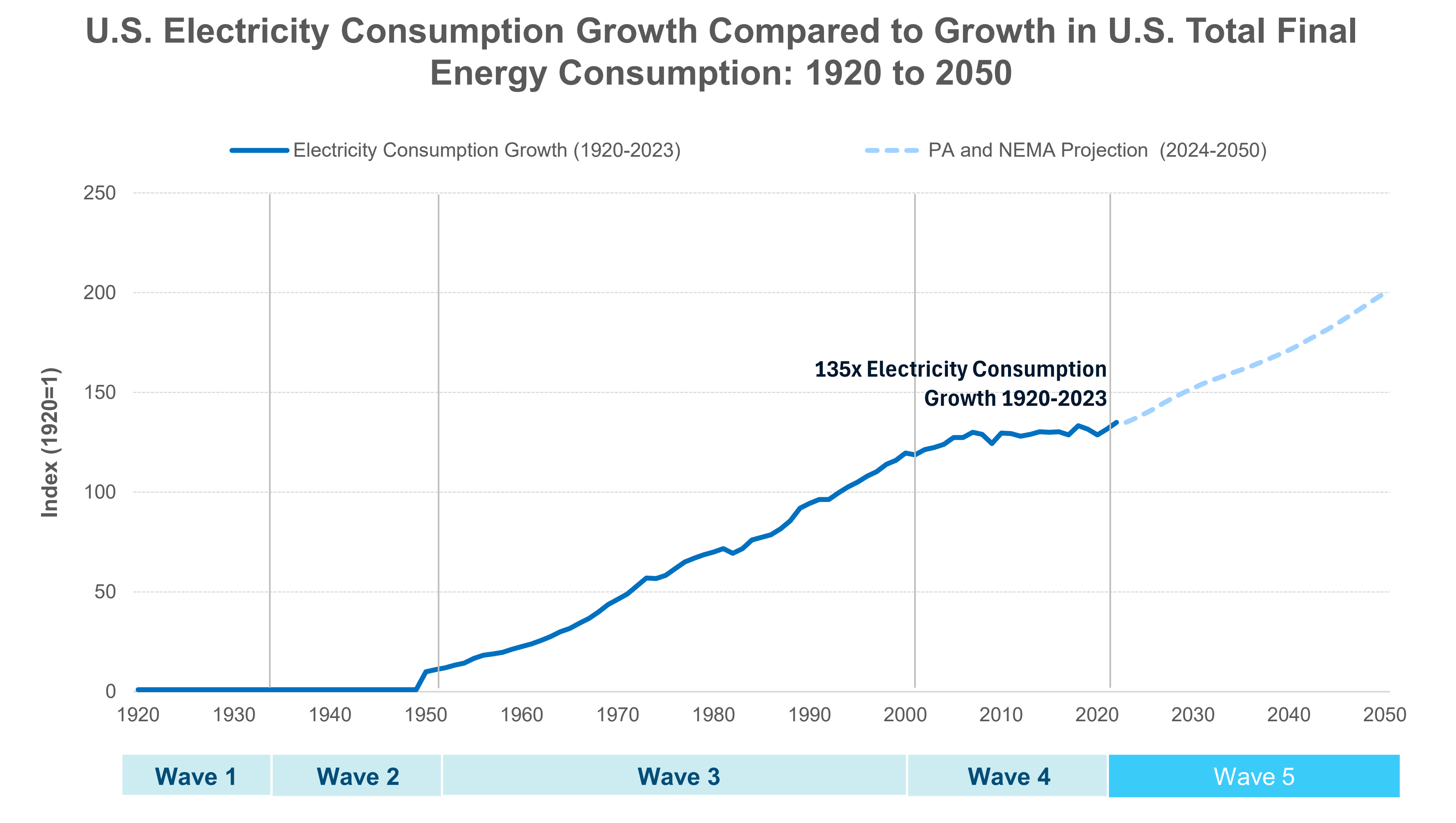
Strategic actions can speed technical solutions adoption:

- Working to enact permitting reform
- Including affordable, clean natural gas in generation mix to ensure 24/7 reliability
- Enabling grid operators and utilities to access existing grid modernization funding and secure new resource—both federal and state government plus private sector
- Adopting policies to foster business sector certainty by establishing markets to encourage technology investments that make the grid more flexible

Grid Flexibility Analysis and Findings

The study highlights technology solutions that can address the growing power shortfall risk over the next five years caused by the congruence of surging power demand and increased reliance on intermittent renewable energy

The United States is at the onset of a new, fifth wave of electricity demand growth that will transform the US energy system for generations to come



- Key drivers of ~2% CAGR growth out to 2050
  - New forms of electricity demand such as data centers
  - Transition of molecule-based energy use to electricity end use e.g., Electric Vehicles
  - Projected population growth
- These drivers will significantly outweigh the role of energy efficiency – which is largely responsible for suppressing electricity demand growth to 0.2% CAGR over the last 25 years

Source: PA Consulting & DOE

Several mature tailwinds are driving these seismic changes in the US energy system

1 Decarbonization of the power sector

- *The first domino in greater electrification*
- *Growth of zero marginal cost renewables acts as a cost / cleanliness catalyst to clean other parts of our economy through electricity*

2 Financial and technical advancements in electrification technologies

- *Operational and cost improvements in technologies that naturally incentivize the move away from molecule-based solutions to electron-based solutions*

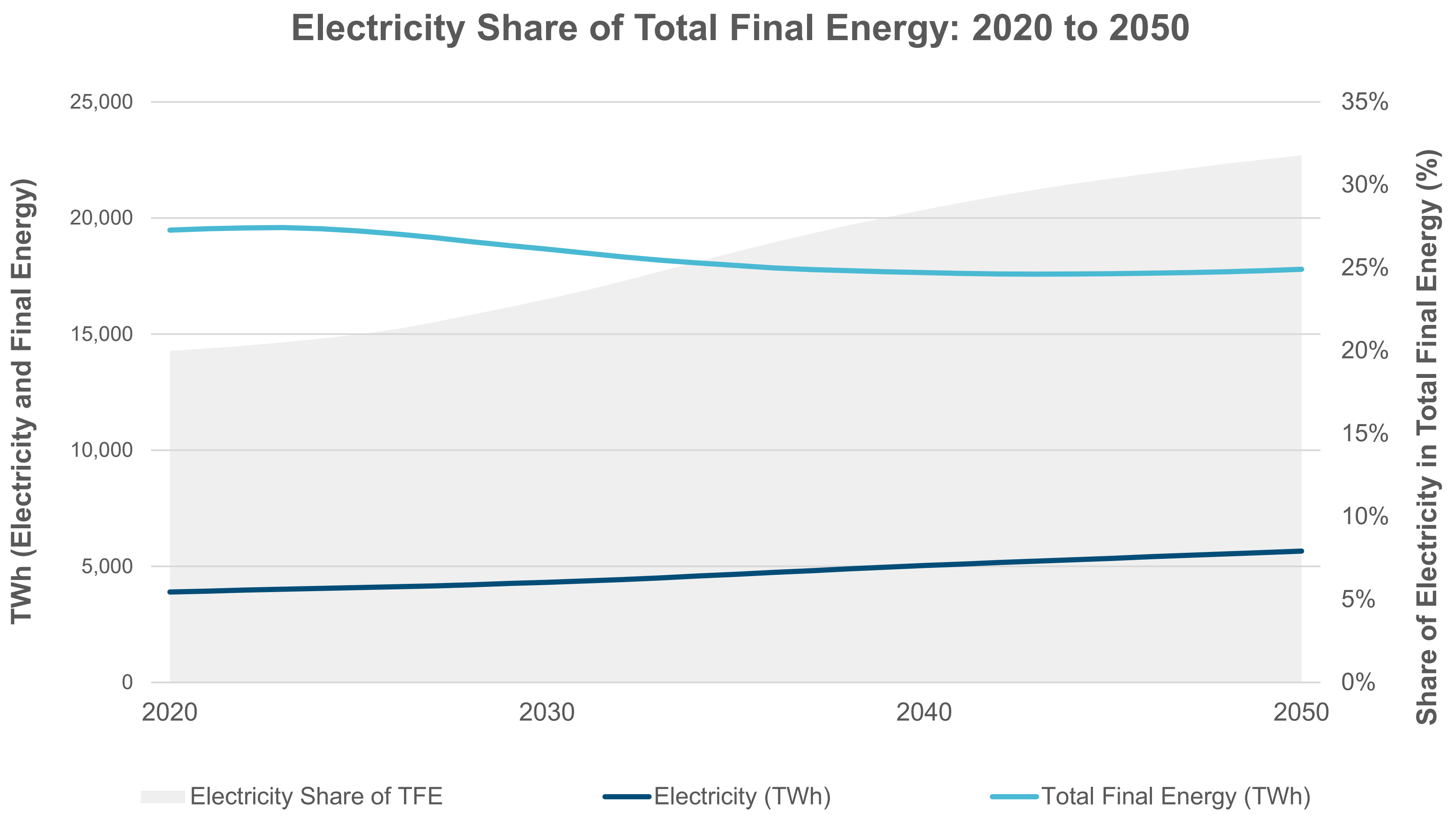
3 Changes in consumer preferences

- *Reflected in both clean energy policy and consumer decision making*
- *Greater choice in the types of energy being consumed and control of when and how to consume that energy*

4 The power of data & the internet

- *Enablers that connect an increasingly complex set of generation, wires and consumption assets*
- *Key to controlling, managing and optimizing the grid of the future*

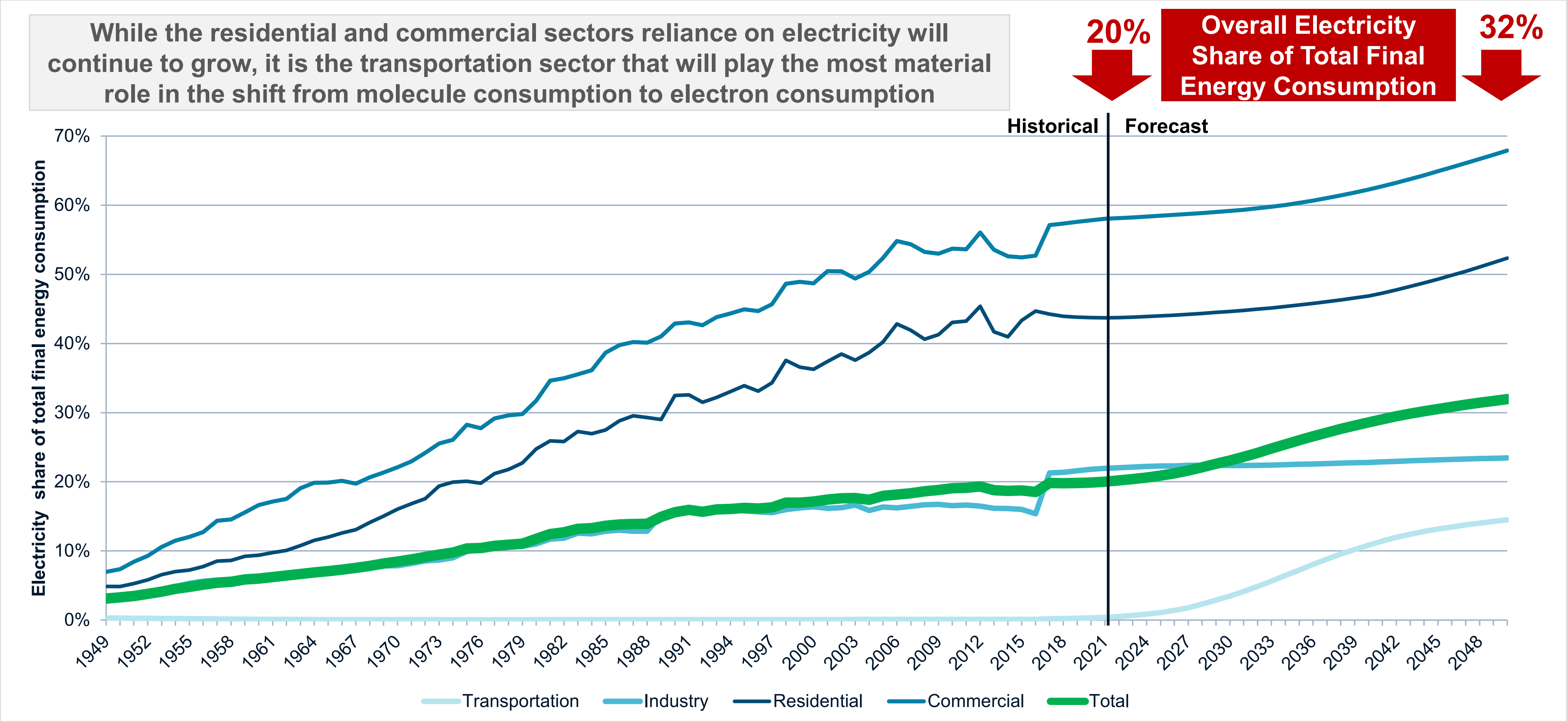
At the center of this transformation is a fundamental shift away from molecules to electrons to meet the economy's energy needs – with electricity contributing 32% of Total Final Energy consumption in 2050 vs 21% today



- Total final energy demand in the US will decline by about 10% - primarily due to the significantly better energy conservation efficiency of EV batteries vs. combustion engines resulting from projected electrification of nearly 200M road vehicles by 2050
- Over the same period, the percentage that electricity will contribute to final energy use in the US will grow from 21% today to approximately 32%

Source: NREL & PA Consulting

Electricity's role in the consumption of all energy in the US will grow by an estimated 60% over the next 25 years



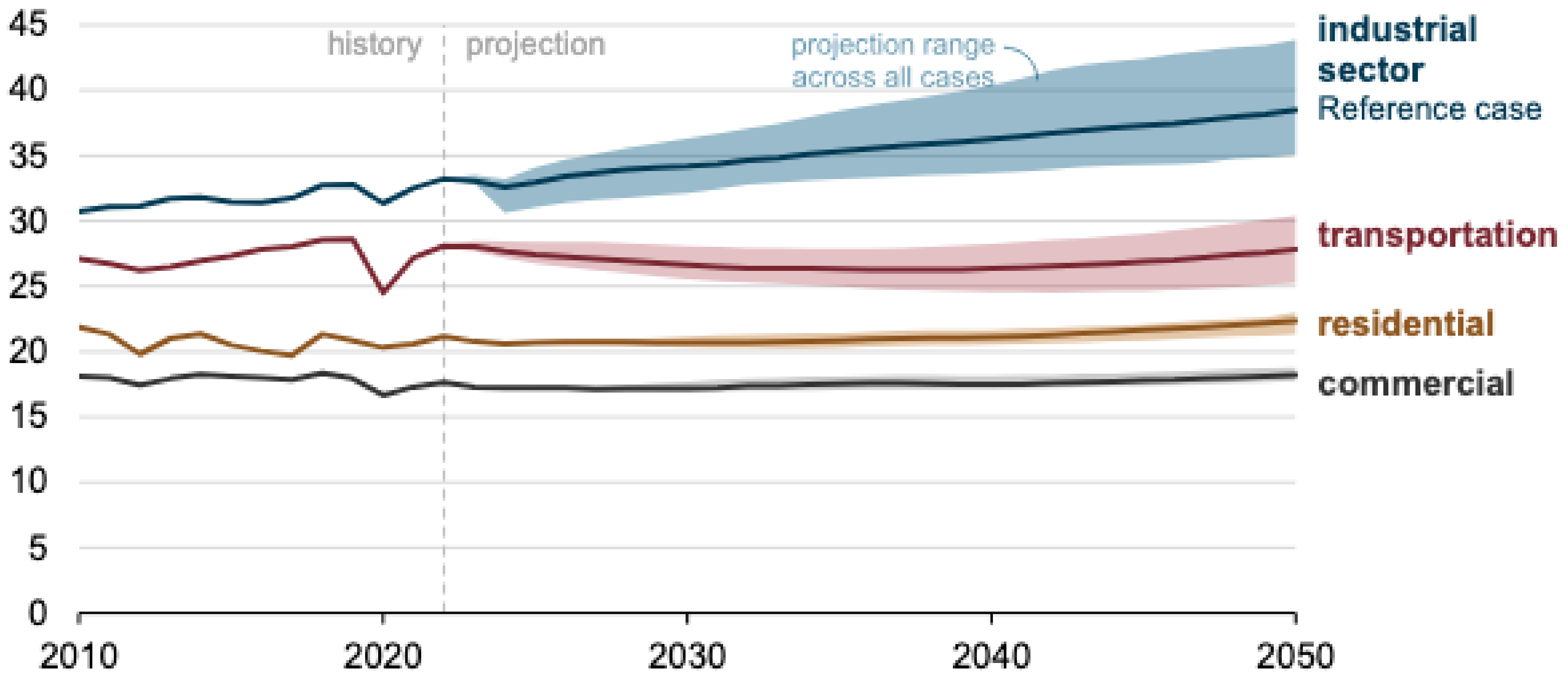
Source: NREL Grid Electrification Study

Total final energy consumption has flattened over the last 25 years despite growth in population and GDP, and we expect this trend to continue out to 2050 – with a strong chance that we will actually see energy consumption start to decline

PA is not as bullish as EIA on energy consumption growth in the industrial sector and is therefore projecting that we may see up to a 10% decline in overall US energy consumption out to 2050.

This will be primarily driven by electrification of transportation (EV's will be somewhere between 31% and 48% more energy efficient that ICE equivalents – depending on US wide electricity generation mix)

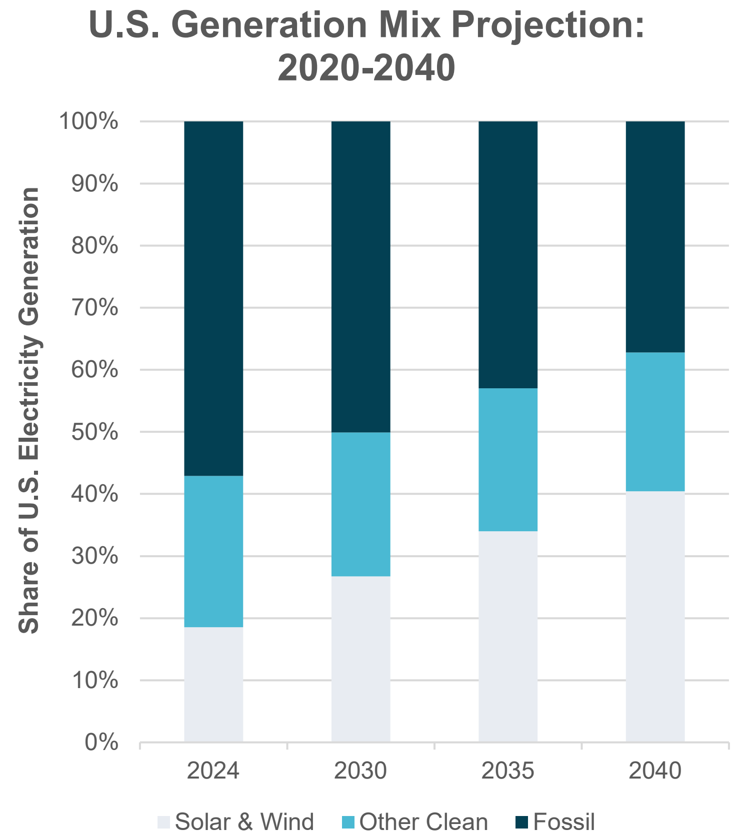
Total energy consumption by end-use sector, USA (2010-2050)
quadrillion British thermal units

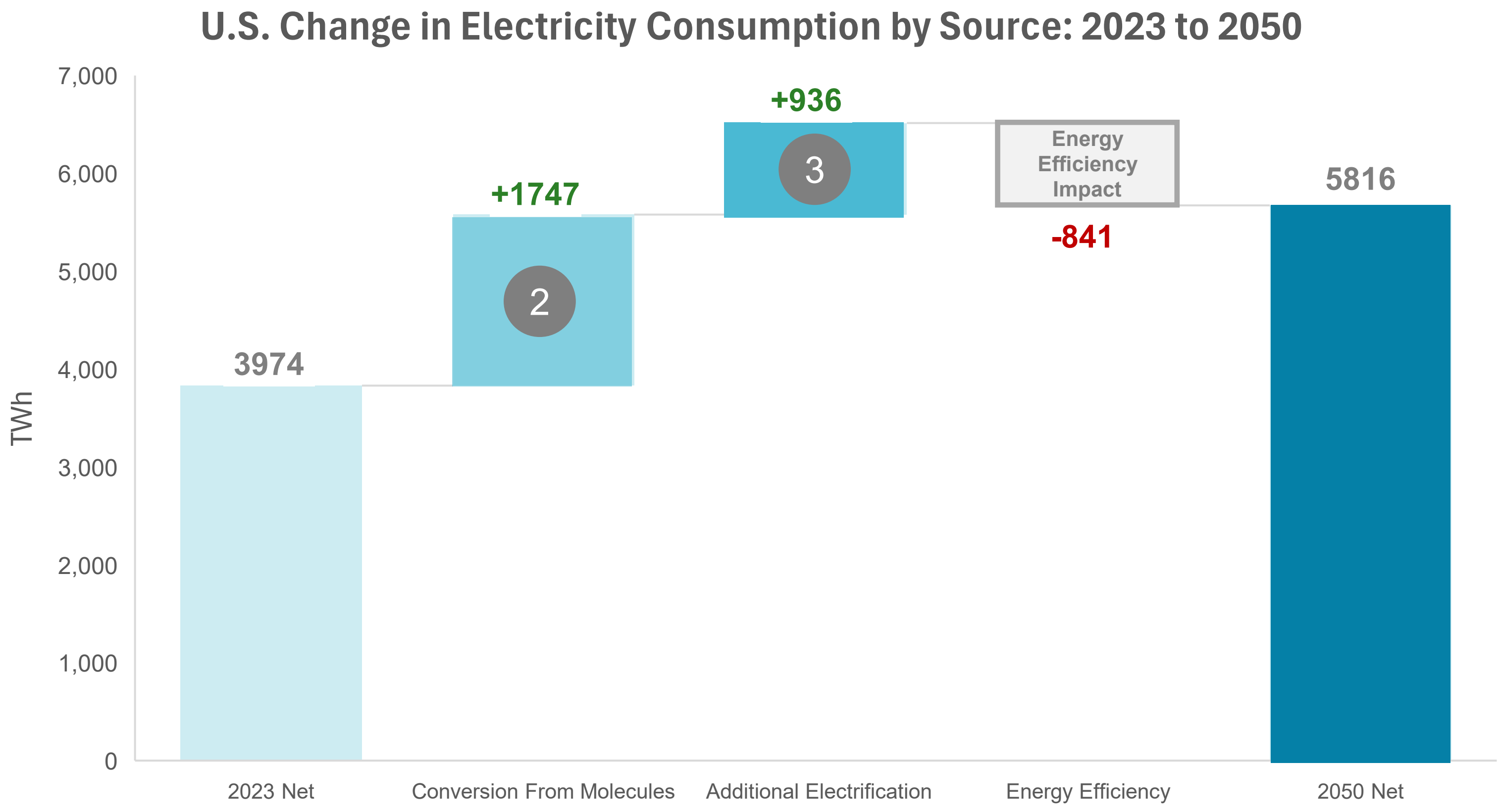


Source: EIA

Putting aside variables like population growth, GDP growth and climate change, three critical factors are driving the shift to greater electrification of our economy

1. The decarbonization of our electricity generation mix making it more attractive to electrify other parts of our economy
2. Cost and operational advancement of technologies that shift demand away from molecules to electrons
3. The introduction of new forms of energy demand that are naturally most suited to be met through electricity

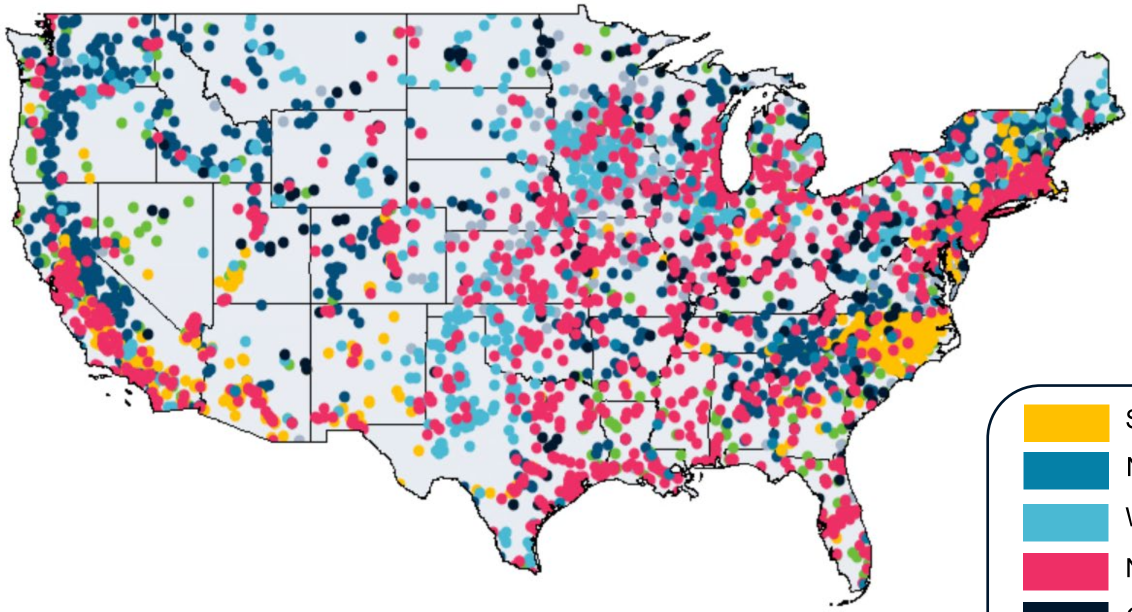




Source: PA Consulting 2024

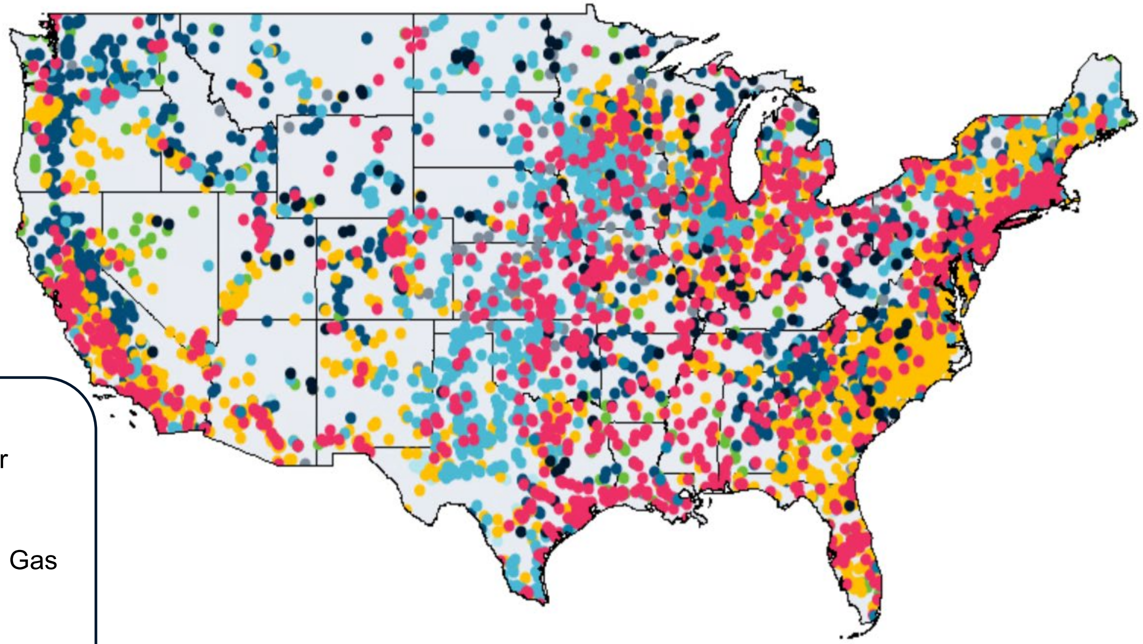
It is not only the sources of bulk grid generation that are materially changing, but the location and individual unit size of that generation

Electricity Generation Resources in 2015

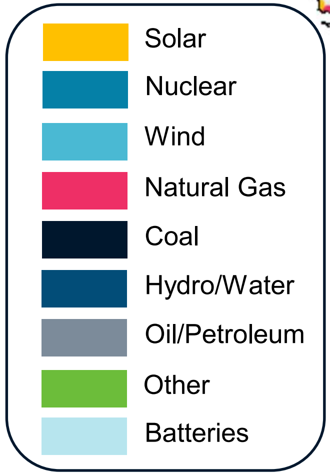


From fewer, larger, dispatchable forms of baseload generation located near to population centers…

Electricity Generation Resources at Present



…to a greater number of smaller, intermittent forms of renewable generation that are typically located farther away from cities

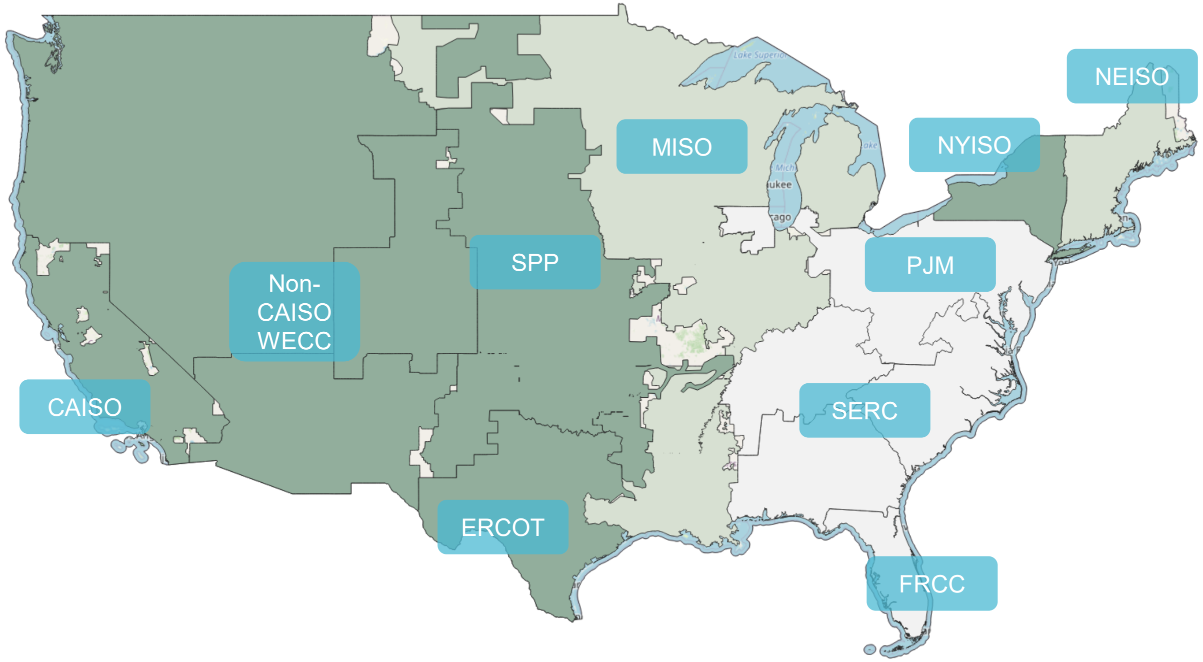


Source: Various

Changes to the US electricity system will not be ubiquitous – the growth of renewables will vary regionally and accelerate at different speeds over the next 20 years

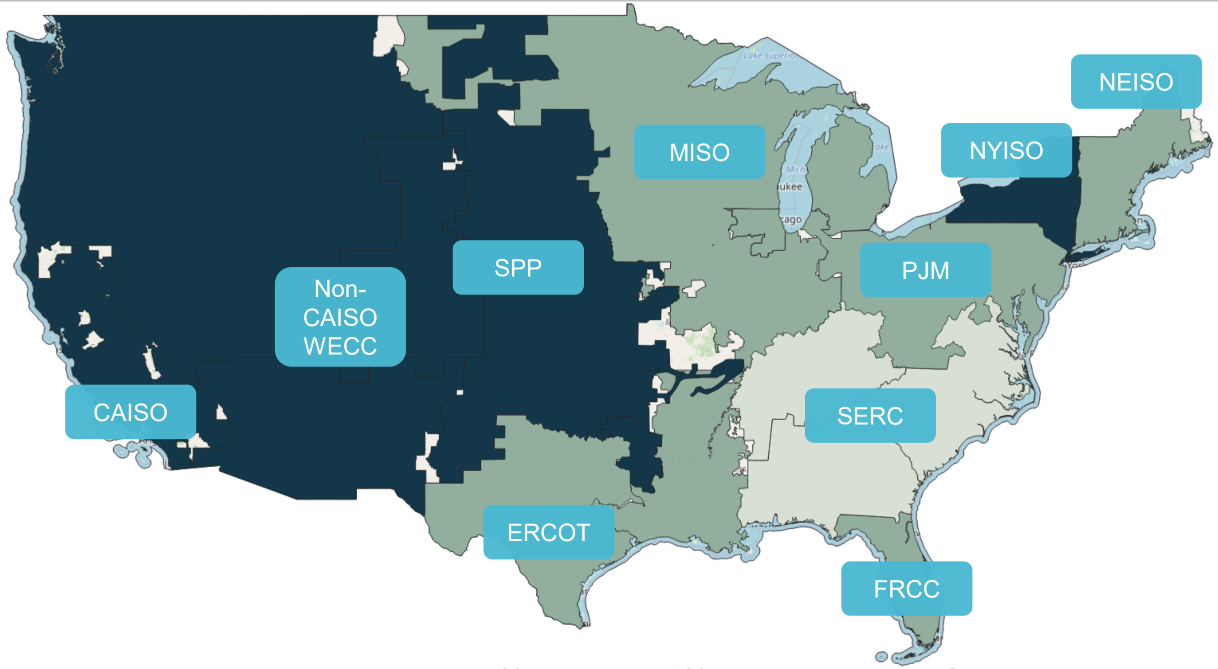
Renewable Generation As A Percentage Of Total Generation – By Region

Present



- Renewable electricity generation % is highest in the Western U.S. and New York
- Renewable electricity generation % is lowest in the Southeastern U.S.
- MISO and NEISO are in the middle of the pack (10-25%)

2040



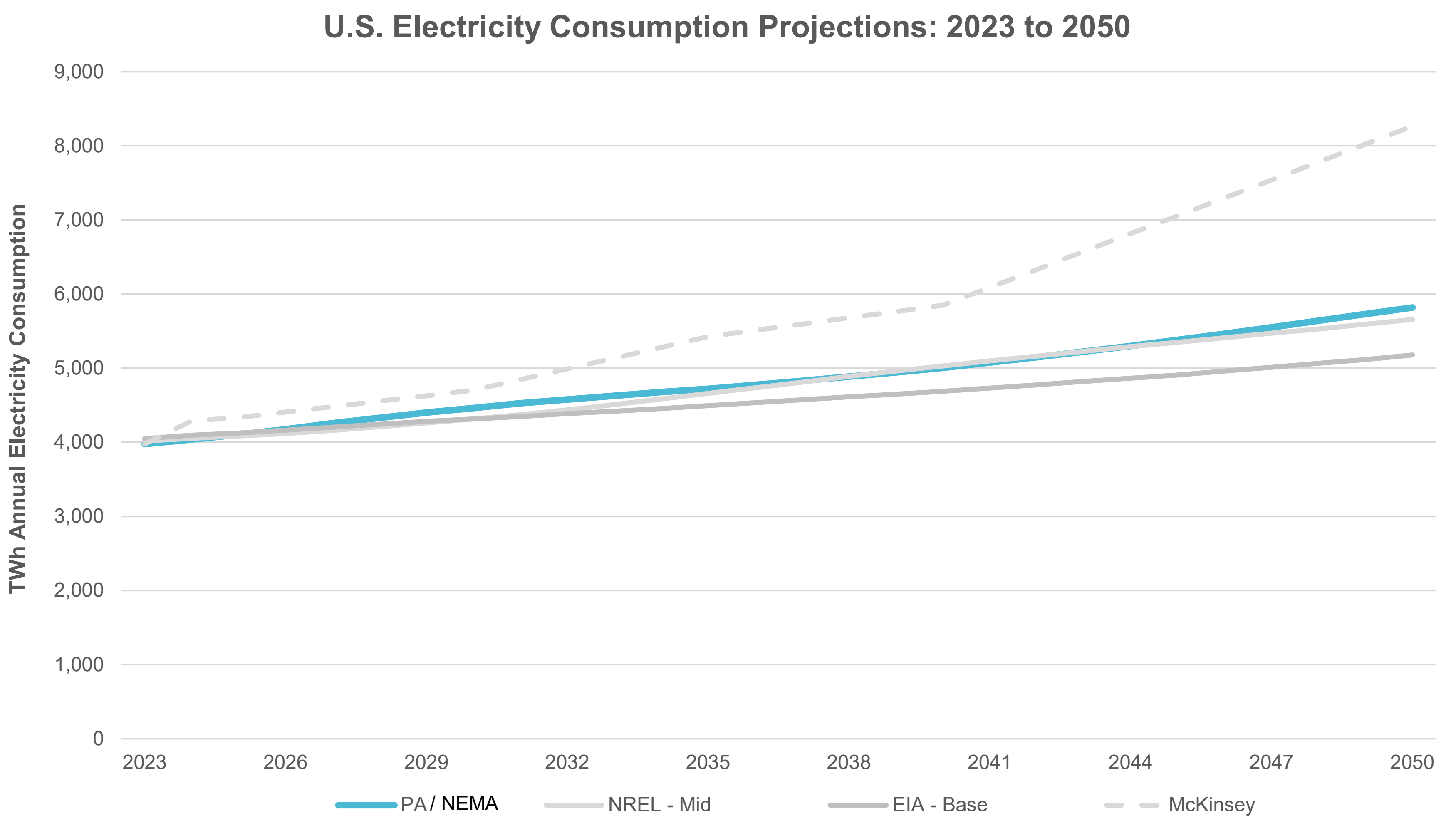
- Renewable electricity generation % exceeds 50% in the Western U.S. and New York, (consistent with their current high penetration), as well as the Southwest Power Pool
- FRCC & PJM jump from the 0-10% into the 25-50% bucket, a ~5-fold increase
- The Southeastern U.S. continues to have the lowest renewable electricity generation %, yet moves into the 10-25% RE Gen % bucket
- ERCOT remains in the 25-50% bucket, though moves from the lower to the higher end

0-10%	10-25%	25-50%	50%+

Source: PA Consulting

Changes in the electricity generation mix and consumer needs will result in a 50% increase in U.S. wide electricity consumption over the next 25 years vs less than 2% over the previous 25 years

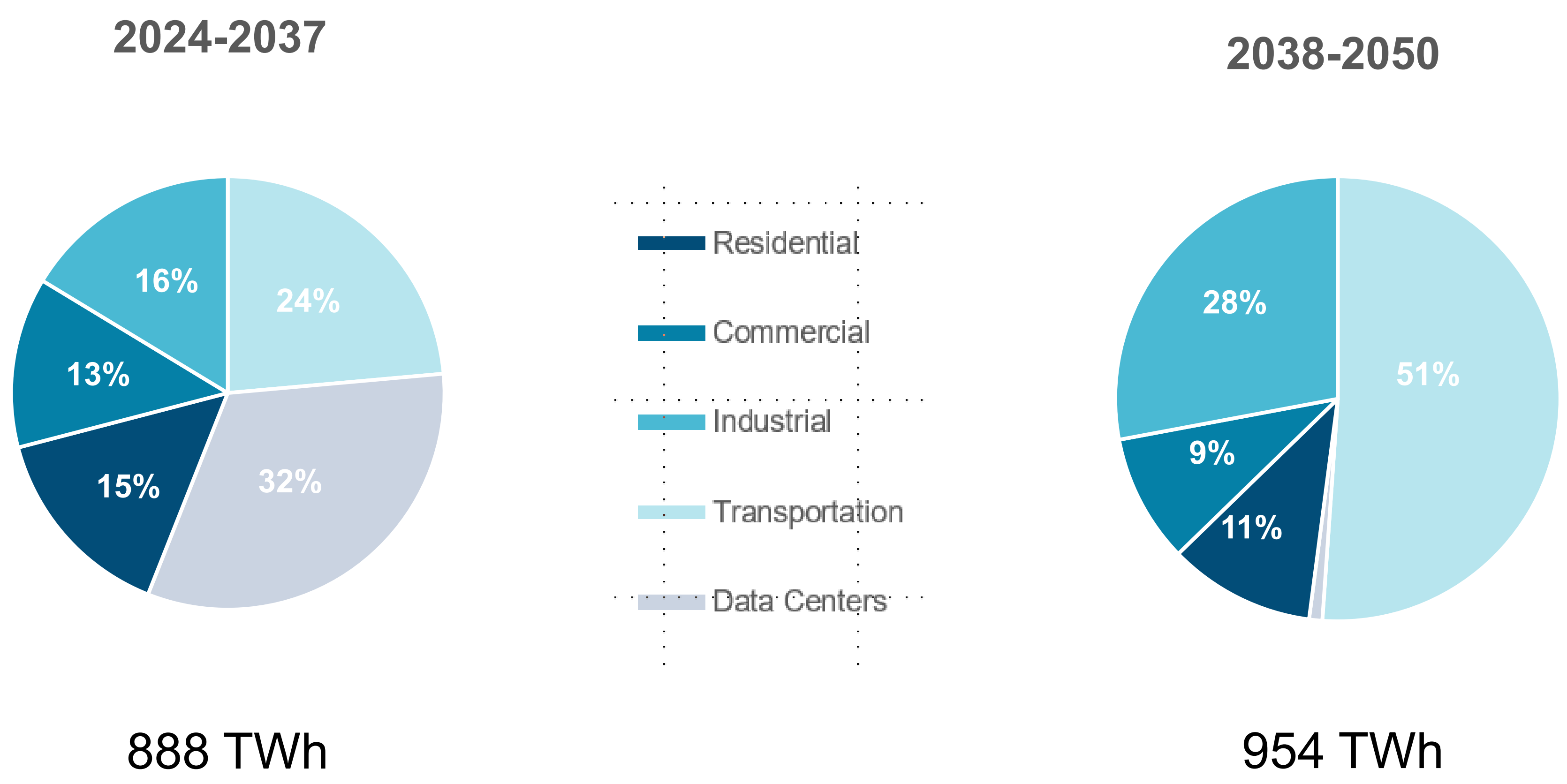
- PA Consulting's' projections are commensurate with those of other credible sources
- Key factors that will determine the accuracy of this projection:
  - More aggressive electrification of the U.S. vehicle fleet post 2035
  - The role of AI and its impacts on further data center growth beyond 2035
  - Commercialization of technologies that allow electrification of industrial heating processes from 2040



Source: PA Consulting 2024, EIA and NREL

The continued emergence of data centers will account for much of the change between now and 2035, with electrification of motor vehicles and further industrial electrification setting the pace from 2035 through to 2050

US Electricity Demand Growth Over Time – Present to 2050



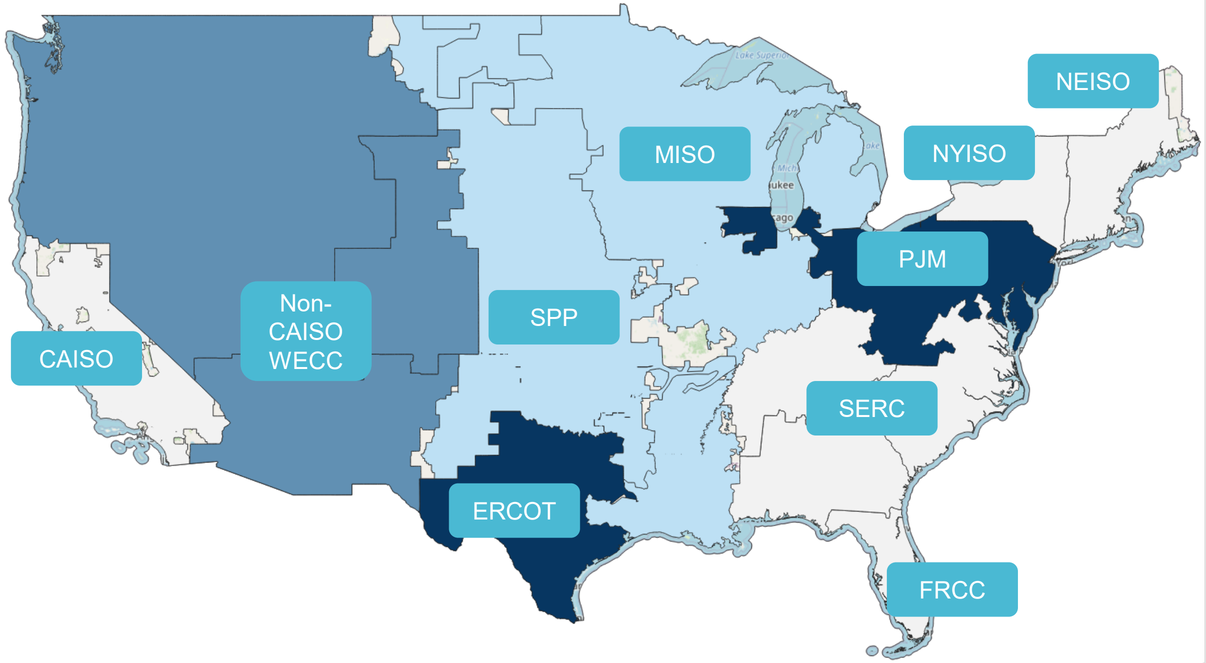
- Over 90% of projected data center consumption growth between now and 2050 will happen in the next decade, although there is much greater uncertainty on what demand growth will look like beyond 2040 and is therefore likely to be conservative
- While EV technology is already commercialized and increasingly reaching price parity with ICE vehicles (particularly LDV's), the average vehicle ownership cycle of 11 years will mean that approximately ¾ of projected transportation electrification to 2050 will take place after 2035

Source: PA Consulting

These changes in consumption will not be ubiquitous across the US, with each region setting their own pace of growth, driven primarily by data centers in the short term, and EVs in the long term

2023-2035 Electricity Consumption Growth

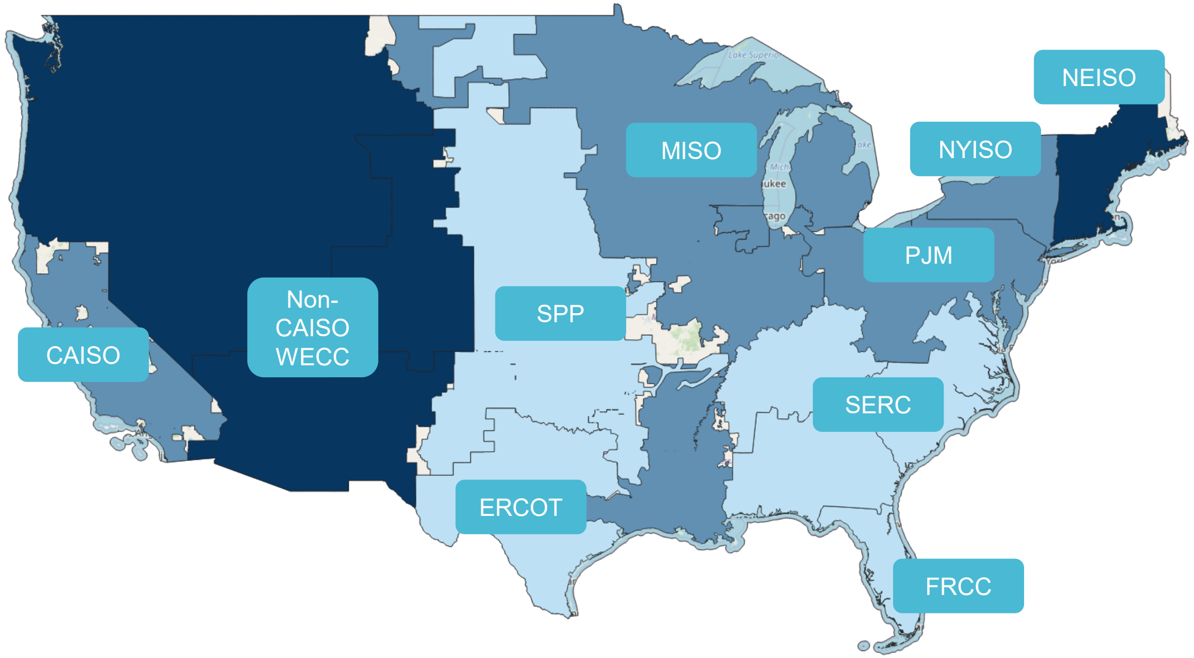
Using 2023 as baseline



- PJM, ERCOT experience the fastest growth (>40%), driven predominantly by data center proliferation
- CAISO and the Southeastern U.S. experience the slowest growth (few data centers, mature energy efficiency initiatives, etc.)

2035-2050 Electricity Demand Growth

Using 2035 as baseline



- EVs drive large changes demand growth in regions like non-CAISO WECC and NEISO, which have lower baseline electricity consumption, yet high projected EV energy demand
- Initially fast-growing regions (ERCOT, PJM) slow down, as data centers saturate

0-10%	10-20%	20-30%	30%+

Source: PA Consulting

The changes in both electricity generation and consumption will result in a 2050 grid that looks very different from the grid of today

LESS CONTROLLABLE ELECTRICITY GENERATION MIX
22% of generation mix will be solar which generates for on average 3-4 hours a day

GENERATION CAPACITY
Increase in boiler plate electricity generation capacity of 43% by 2040

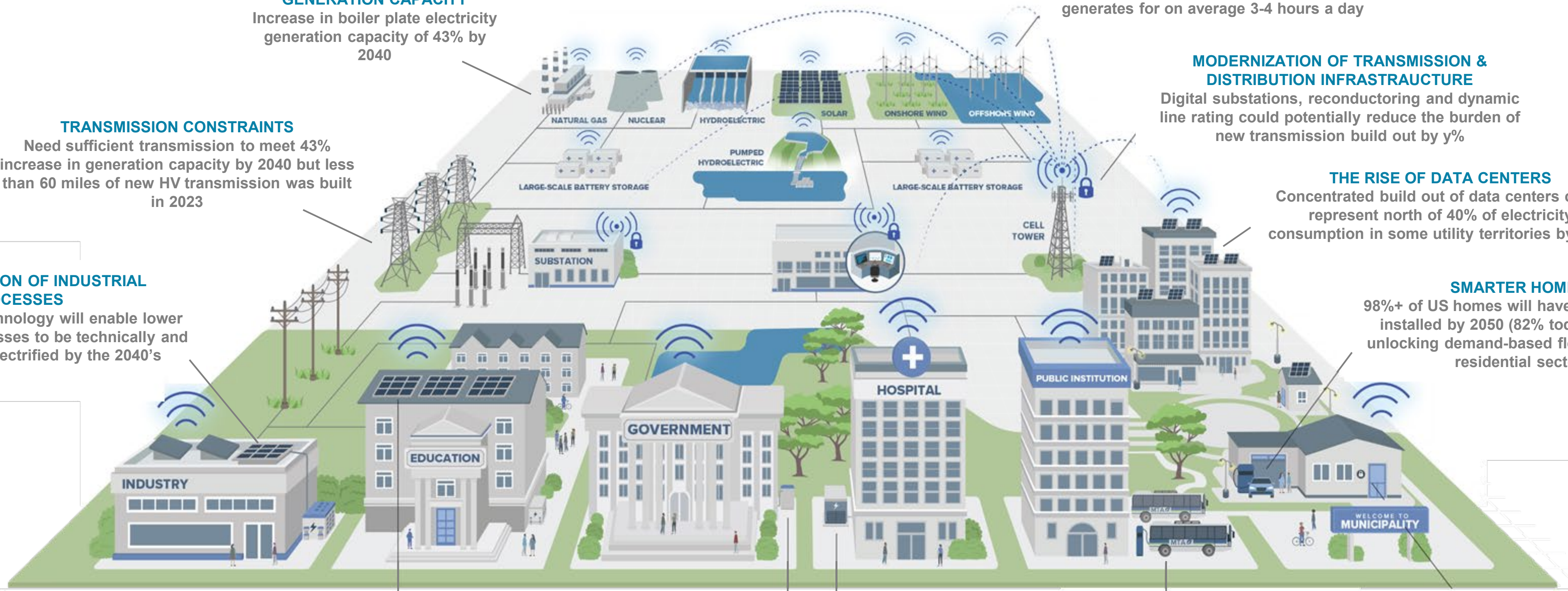
MODERNIZATION OF TRANSMISSION & DISTRIBUTION INFRASTRAUCTURE
Digital substations, reconductoring and dynamic line rating could potentially reduce the burden of new transmission build out by y%

TRANSMISSION CONSTRAINTS
Need sufficient transmission to meet 43% increase in generation capacity by 2040 but less than 60 miles of new HV transmission was built in 2023

THE RISE OF DATA CENTERS
Concentrated build out of data centers could represent north of 40% of electricity consumption in some utility territories by 2035

ELECTRIFICATION OF INDUSTRIAL PROCESSES
Advancement in technology will enable lower heat industrial processes to be technically and cost effectively electrified by the 2040's

SMARTER HOMES
98%+ of US homes will have smart meters installed by 2050 (82% today) – key to unlocking demand-based flexibility in the residential sector



LOCAL BEHIND THE METER SOLAR GENERATION
More than 5% of all electricity consumption needs met from behind the meter solar resources by 2050

BATTERY STORAGE
11 times more storage capacity will be deployed on to the grid in between now and 2040

ELECTRIFIED TRANSPORTATION & CHARGING INFRASTRUCTURE
200 Million Electric Vehicle on US roads by 2050

FURTHER ELECTRIFICATION OF HOME HEATING & COOLING
Resulting in up to 70% of all home devices and energy assets having demand-based flexibility

Source: PA Consulting 2024 & NYPA 2021

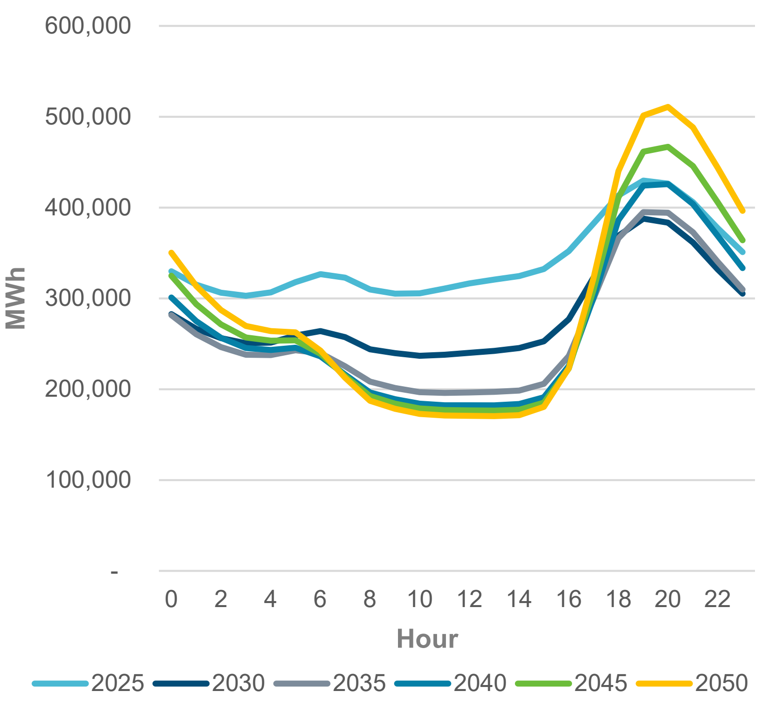
The size of the challenge should not be underestimated – and new generation and transmission alone will not ensure reliability through the end of the decade

	Today	2050	Implications
Percentage of renewable electricity generation	15%	54%	• Doubling of bulk grid generation capacity that needs to be met through transmission and distribution wires • Only 55 miles of new transmission in 2023
Percentage of electricity generation capacity that is realistically dispatchable	57%	<20%	• Insufficient controllable generation to meet unpredictability in supply and demand • Overall, less responsive generation fleet
Net electricity consumption	3974 TWh	5816 TWh	• Greater pressure on the generation, transmission and distribution grid to meet new forms of demand – particularly at certain times of the day
Percentage of total energy consumption in the average home derived from electricity	44%	64%	• Greater local reliability of electricity grid required to provide basic services to homes and businesses
Typical maximum growth in net electricity consumption over a three-hour period (4pm to 7pm)	31%	124%	• Sharper and more aggressive peaks in electricity consumption growth require faster, more responsive and controllable solutions

Source: PA Consulting 2024

The 2050 electricity grid will present different reliability and affordability challenges to those responsible for managing the grid compared to today

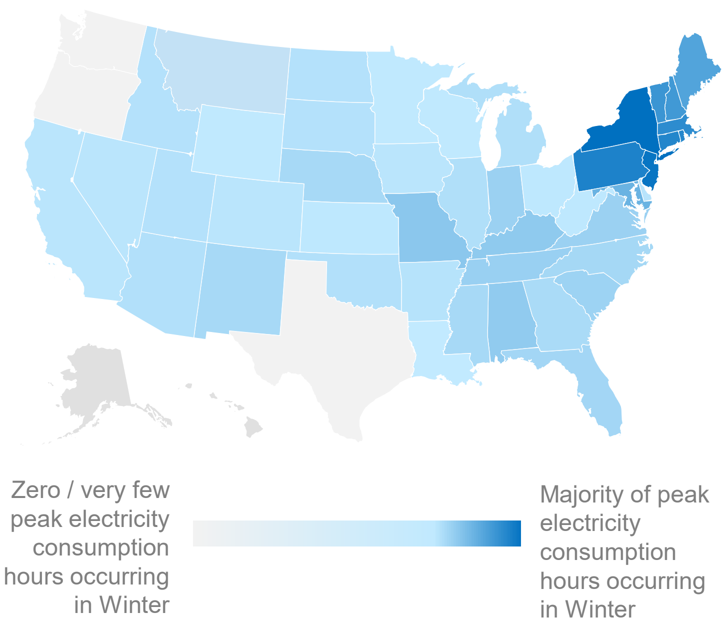
US Hourly Net[1] Average Electricity Consumption (2025 to 2050)



More aggressive peaks in demand for electricity when the sun isn't shining requiring fast response bulk generation to fill in when solar generation isn't available

[1] Net electricity consumption projections are calculated by subtracting solar generation and energy efficiency from gross electricity consumption demand

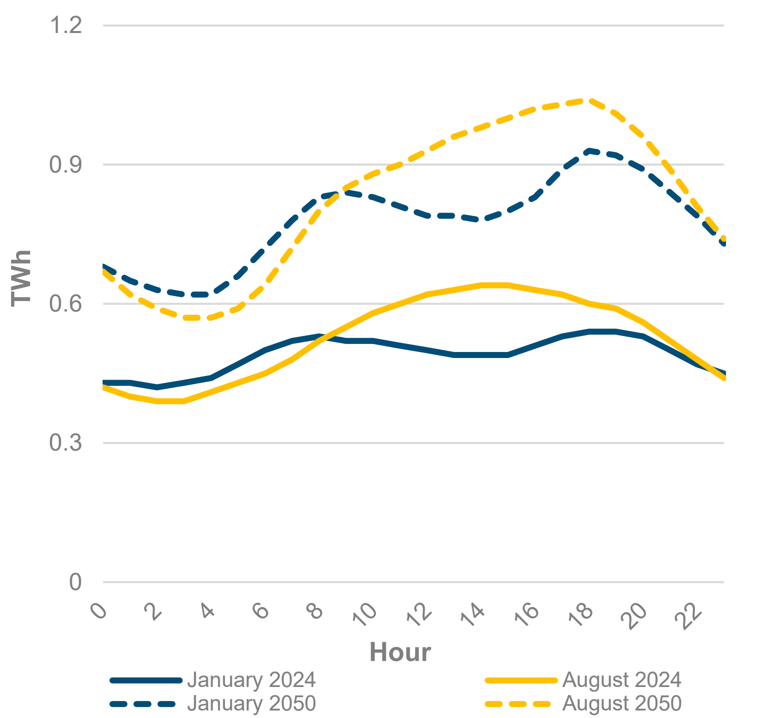
Changing Seasonal Shift In Electricity Consumption Peak - 2050[2]



By 2050, the majority of US states will be shifting towards a winter electricity consumption peak – when reliability and generation resource certainty is even more critical to daily lives

[3] Intensity of color will dictate how many of the peak hours of electricity consumption a year fall in Winter months

US Hourly Average Electricity Consumption[3] (2024 and 2050)



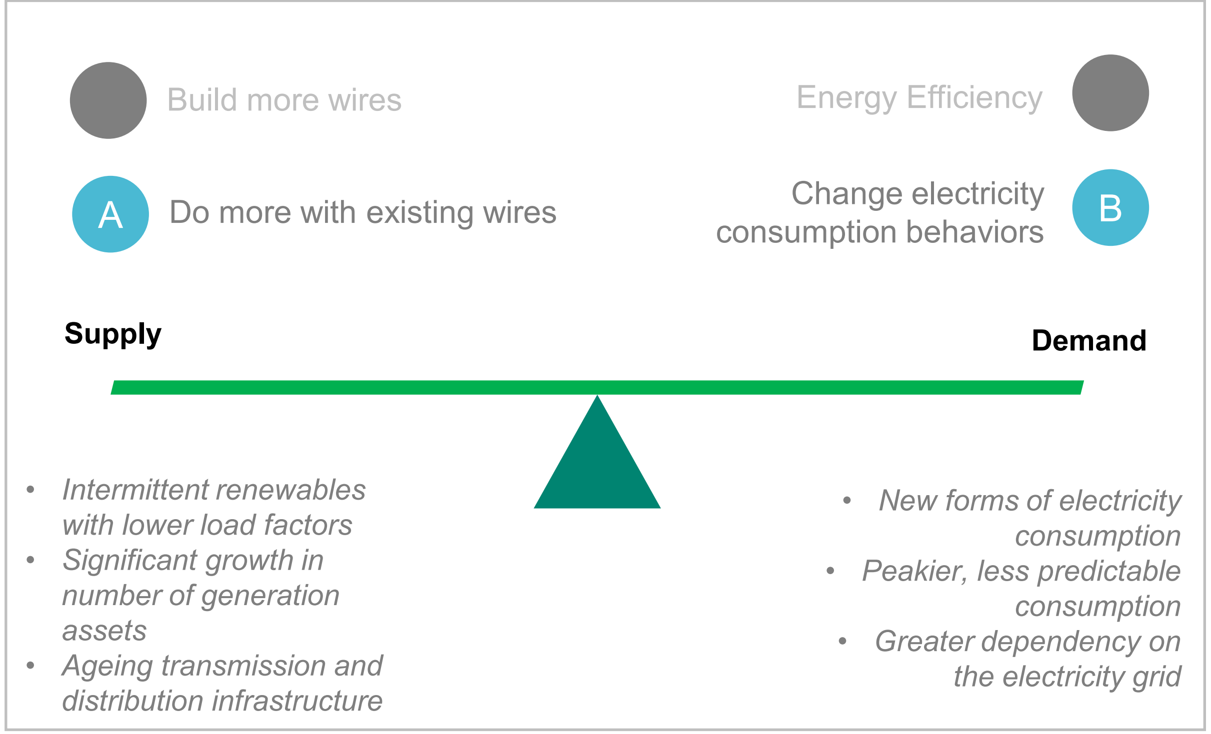
A shift to two distinct peaks in electricity consumption a day in the winter months with peak consumption between summer and winter increasingly narrowing

[3] Electricity consumption calculated by subtracting energy efficiency from gross electricity consumption projections.

Source: PA Consulting 2024

Given the understood timing and cost constraints of building new transmission and the practical limitations of energy efficiency, the electric utility industry has two other levers to keep pace with the projected changes in the US electricity system

The Electricity Supply and Consumption Equilibrium



A Do more with the wires that we already have - use technological advancements, data & AI to increase the potential capacity and resilience of our existing transmission & distribution system

B Focus on changing when, where and how humans consume electricity at times – particularly where the grid is under pressure to meet consumption

- Temporarily reduce consumption
- Shift consumption to non-peak parts of the day
- Store excess generation and release when the grid is stressed

These alternative solutions are about creating a much more flexible electricity grid – one that can better respond to uncertainty & mismatches between supply and consumption – and if used correctly can be an incredibly cost-effective way to address both supply and consumption-based challenges

There is a large list of potential solutions that could be deployed to solve the grid imbalances caused by growth in new forms of electricity demand and a low carbon generation mix

Challenges

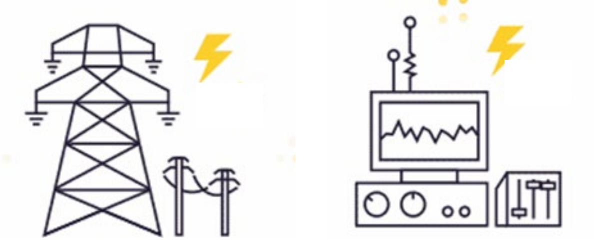
- Greater proliferation of intermittent, less controllable renewable generation makes it more difficult to respond to dynamic changes in electricity consumption
- Doubling of current generation capacity by 2040 to meet growing electricity needs and lower load factor of renewables
- Renewable generation located further from cities presenting additional reliability challenges

- Existing transmission system is ageing
- It is taking on average 15 years to build new transmission lines
- In the US Only 55 miles of new transmission was operationalized in 2023
- As our economy and lives become increasingly reliant on electricity, reliability of the wires also becomes more important

- Electricity consumption is going to grow by nearly 50% in the next 25 years
- This growth in consumption is not going to be ubiquitous geographically or across the typical day placing new capacity and peak management challenges on the electricity grid that the intermittent and geographical location nature of renewable generation is not best suited to address

Grid Components

GENERATION



TRANSMISSION, DISTRIBUTION & SYSTEM MGMT

CONSUMPTION

10Yr Horizon Solutions

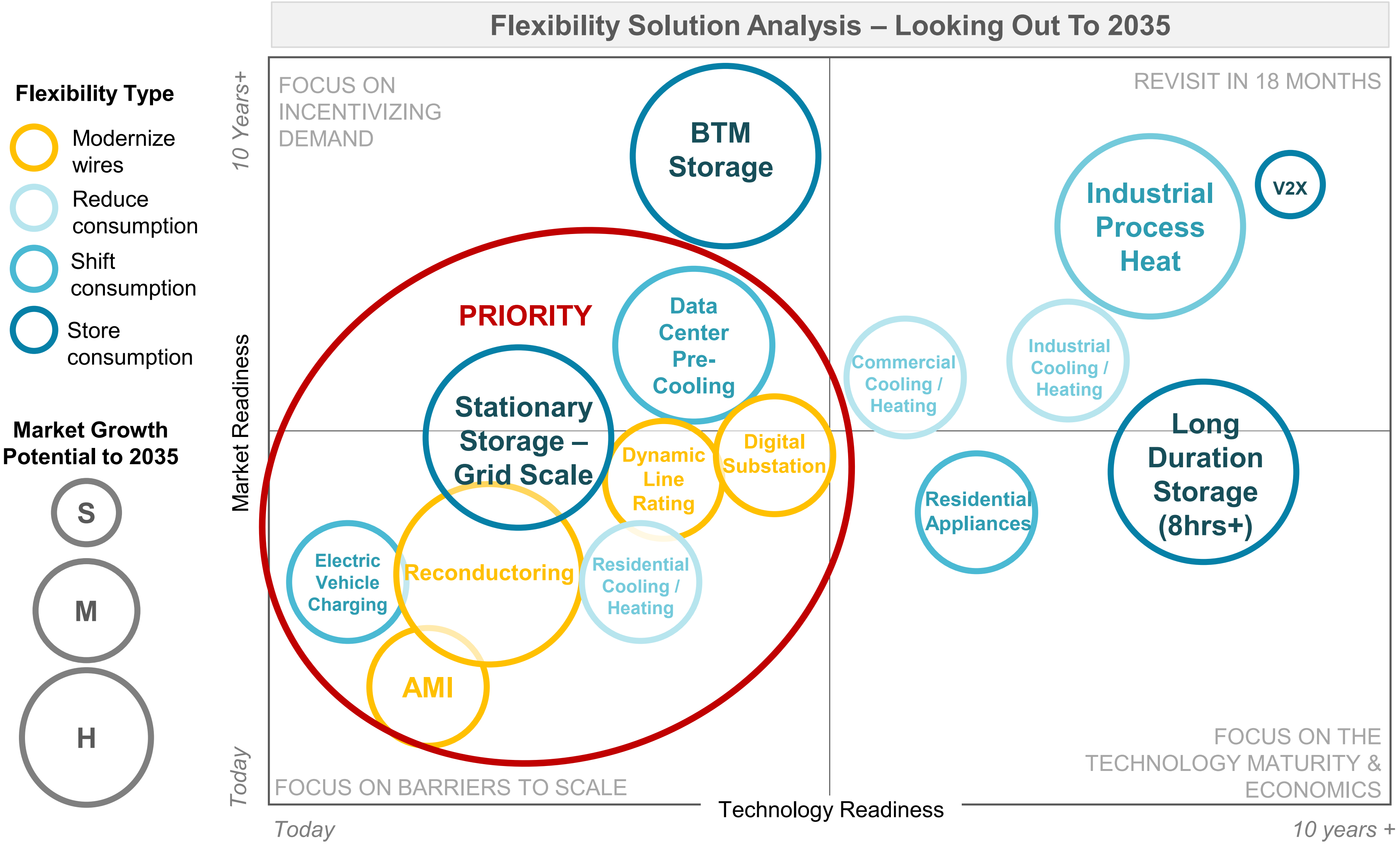
- Overbuild of renewable generation (*not in scope of study)*
- Large, longer duration grid scale storage
- Commercialization of a new form of low carbon dispatchable generation e.g. small modular nuclear or geothermal (*not in scope of study*)

- New transmission & distribution (*not in scope*)
- Advanced Metering systems
- Dynamic Line Rating
- Reconductoring of transmission wires
- Digital substations

- Continued improvements in energy efficiency (not in scope)
- Shifting of cooling and heating to nonpeak hours
- Shorter and longer duration BTM storage
- Shifting of EV charging to nonpeak hours
- Temporary reduction in electricity consumption

Source: PA Consulting,

Between now and 2035, prioritizing areas of grid flexibility investment will be key to managing the changes in electricity supply and demand – ensuring continued reliable and cost-effective management of the electricity grid



Technology Readiness:
- Addresses the level of technology or solution maturity through the lens of to what extent the technology has been tested for operational feasibility, to what extent one off deployments have demonstrated financial and operational benefit and experience of deployment at scale

Market Readiness:
- Level of ease and financial incentive for customers to participate
- Level of utility desire to enable deployment of solutions in their territory
- Complexity of energy asset deployment
- Barriers to aggregate and scale

Market Growth Potential:
- Looks at supply and consumption projections
- Looks at published market CAGR's where applicable

Source: PA Consulting 2024

To scale grid flexibility over the next decade to a point where it can provide a material role in maintaining an affordable, reliable and increasingly decarbonized grid, the following technologies can play a leading role

Wires Flexibility Area	Description, Size & Estimated Value	Barriers to Scale
AMI	Critical for enabling control of customer electricity consumption and utilization of behind the meter grid assets **130 million smart meters already installed** (over. 80% of all bill payers). Projected **11.2% CAGR out to 2027**)	• *Market penetration of AMI's is already north of 80%* • *Remainder of roll out dependent on utilities ability to rate base the cost of installation* • *Barriers to releasing the value of AMI requires a) improved smart and connected electrical appliances in the home / business and utility incentivization to harness the power of the data that AMI can provide*
Reconductoring Transmission Lines	Replacing conventional aluminum conductor steel reinforced transmission cables with advanced conductors could theoretically enable the US to get **90% of its electricity from emissions-free power sources by 2035.**	• *Sufficient economic attractiveness for transmission owners to select this as a solution vs. building (and rate basing) new transmission infrastructure* • *Better, more coordinated transmission planning and needs assessment to understand where reconductoring could be an operational and economic viable option*
Dynamic Line Rating	Enables greater real time accuracy of electrical conductors **Almost all lines will see at least 10% more capacity 90% of the time, and the average increase in capacity can be 30-50%** with favorable climate and geography	• *Sufficient economic attractiveness for transmission owners to select this as a solution vs. building (and rate basing) new transmission infrastructure* • *Better, more coordinated transmission planning and needs assessment to understand where reconductoring could be an operational and economic viable option* • *Expand beyond current pilot projects into mainstream*
Digital Substations	Application of modern sensors, communication networks, digital technology to substations. North America Industrial Digital Substation Market was **valued at USD 1.1 billion in 2023** and is projected to expand at a **CAGR of 6.1% between 2024 and 2032**	• *Sufficient economic attractiveness for distribution network owner / operators to select this as a solution vs. building (and rate basing) new substation build out* • *Greater deployment of DER's and EV's to create demand for digital substation use cases and utility DERM's solutions to tap into digital substation value*

Source: PA Consulting & Various 2024

To scale grid flexibility over the next decade to a point where it can provide a material role in maintaining an affordable, reliable and increasingly decarbonized grid, the following technologies can play a leading role

Demand Flexibility Area	Description, Size & Estimated Value	Barriers to Scale
Electric Vehicle Battery Load	Shifting **10% of daily charging load (3 million EV's)** from peak to nonpeak consumption hours could remove the need for **approximately 40GW of additional generation capacity.**	• *Charging and communication standards (including integration with utility systems or home energy management ecosystem)* • *Battery warranties (no level of reasonable compensation for grid services will overcome any concern about degradation to vehicle)* • *Utility policies/comp mechanisms – currently only 6% of the US utility footprint has a residential V2G program today.*
Stationary Battery Storage	30GW projected storage capacity by 2040 could yield **~$2.0B in energy arbitrage and capacity value** to the U.S. electricity system as well **as 4 MMT GHG/yr.** in emissions avoidance.	• *Commercialization of longer duration storage (4+ hours) -> higher ELCC* • *Development of clear, compelling commercial and residential storage-specific electricity tariffs* • *Creation of direct utility to customer marketplace to animate consumer participation*
Data Center Cooling Electricity Load	Shifting **~ 15% cooling load** of a standard 180MW data center from on-peak to off-peak times would save an estimated 1.97% of generation charges, or **$635,000 a year.**	• *Proof of concepts – that data centers can shift cooling load without compromising reliability and down time of the facility* • *Utility tariffs and rates that are a sufficient to incentivize participation – particularly for short periods of extreme peaks* • *Other incentives such as making the data center owner responsible for grid / capacity upgrades -> grid flexibility is a cost-effective alternative*
Residential Electricity Load	Shifting a small share of residential load for **51 hours over 9 days** in the summer could **reduce peak demand in MISO by at least 8 GW** – with a conservative estimate of **~$169M** savings for customers per year.	• *Building codes and standards for new construction to favor electrification, energy efficiency and consumption-based flexibility* • *Standardizing communication protocols for devices* • *More intelligent and automated demand management utility tariffs and programs to enable scale*

Source: PA Consulting & Various 2024

Our analysis suggests the following grid flexibility technologies priorities for the industry over the next 3-5 years – in order

Flexibility Area		Definition	Rationale
1	Reconductoring of Transmission Lines	Replacing conventional aluminum conductor steel reinforced transmission cables with advanced conductors can help add additional capacity to existing transmission lines	• *Additional transmission capacity from reconductoring could allow the United States to get 90% of its electricity from emissions-free power sources by 2035 at 20% of the cost of building new transmission* • *Technology is already proven*
2	Coordination of EV Charging	Shifting a minimum of 10% of daily electric vehicle charging load (3 million EV's by 2050) from peak to nonpeak consumption hours.	• *Could remove the need for approximately 40GW of generation capacity by 2050 (approximately 7% of expected additional generation capacity)* • *The technology to automate charging times for vehicles already exists – making it easy for drivers to participate on a consistent basis.* • *Light Duty Vehicle utilization is on average less than 5% meaning that the EV battery is rarely being used for driving during non-peak electricity hours (overnight / during 11am-2pm)*
3	Deployment of Stationary Storage	Install grid scale and behind the meter stationary storage to a) provide greater resource certainty for renewable generation - increase in load factor and ability to dispatch; b) unblock transmission / distribution substation capacity bottlenecks; and c) provide local resilience and energy arbitrage for homes & businesses.	• *It is expected that there could be in the region of 200GW of storage deployed on the US grid by 2040* • *Just 30GW of this could yield in the region of ~$2.0B in energy arbitrage and capacity value to the U.S. electricity system as well as 4 MMT GHG/yr. in emissions avoidance if used correctly*
4	Deployment of Digital Substations	Replacing or complementing existing substations with the application of modern sensors, communication networks, digital technology, and intelligent devices to monitor, control, and manage distribution & grid edge electrical assets.	• *Digital substations cost less to deploy than physical substations are safer, easier to maintain and provide granular access to real time data – and critical to tapping into the potential value of behind the meter electrical assets in optimizing the matching of electricity supply and demand*

Source: PA Consulting 2024

Our analysis suggests the following grid flexibility technologies priorities for the industry over the next 3-5 years – in order

Flexibility Area		Definition	Rationale
5	Optimization of Residential Appliance Usage	Shifting a small share of residential electricity use for non-critical appliances to non-peak electricity use times or temporarily reduce electricity consumption during peak electricity use times by raising AC temperatures or lower heating temperatures.	• *Reduces peak demand for electricity (and therefore the need for additional generation capacity and transmission capacity)* • *Could also reduce electricity kWh costs for consumers* • *For example, shifting or temporarily reducing residential electricity use for 51 hours over 9 days in the summer could reduce peak demand in MISO by at least 8 GW – with a conservative estimate of ~$169M savings for customers per year.* • *One million smart thermostat customers participating in a demand response program can potentially deliver about 1,000 MW of generation need – that's equivalent to a single, large coal-fired power plant being removed from the grid or 2000-3000 MW of avoided renewable generation* • *Control technologies already exist to automate this in the home and utility residential demand response programs are already being utilized in 10M homes in the US – but that still leaves 140M+ (including new build) untapped potential*
6	Deployment of dynamic line rating technologies on the transmission grid	Enables the rating of electrical conductors to be calculated based on local weather conditions rather than using "worst-case" assumptions of weather conditions	• *Avoid permitting, right of way, cost and other issues that traditionally prevent transmission build out*
7	Optimization of Data Center Electricity Use	Shifting a small percentage of data center cooling load away from peak electricity consumption hours to earlier in the day when clean electricity generation supply is more plentiful could help reduce the need for additional generation and transmission capacity, clean up their carbon footprint and save on electricity bills.	• *Data centers present the most pressing risk to the electricity grid over the next 10 years – albeit concentrated over a small area* • *Shifting ~ 15% cooling load of a standard 180MW data center from on-peak to off-peak times would save an estimated 1.97% of generation charges, or $635,000 a year.* • *Given concentration of data centers and the amount of electricity they need to operate, both the utility and data center owner / operator should be motivated to find solutions to build these facilities as quickly as possible*
8	Continued deployment of AMI	Integrated, fixed network system that enables more granular energy measurement / control & two-way communication between the utility and their customers	• *Technology has already been rolled out across 80% of bill paying locations across the US – wouldn't require timely and costly roll out* • *Its more about harnessing the data that AMI provides to better optimize electricity use and connecting AMI to both the utilities DERM's systems and behind the meter smart electrical appliances* • *Critical infrastructure if we are to move to true 8760, real time management of electricity consumption*

Source: PA Consulting 2024

The call to action – specific activities around the prioritized grid flexibility technologies that NEMA should pursue

	Flexibility Area	NEMA Actions
1	Reconductoring of Transmission Lines	• Work with the utility regulator (maybe through a series of workshops) to educate them on the value of reconductoring vs. new build and to ensure that as part of any utility rate case approval or transmission development project approval, that a clear financial and operational rationale is provided for why reconductoring investment is not appropriate • Work with the DOE to make funding available for these technologies more readily available and attractive to utilities and project developers • Work with entities (key universities and the IBEW etc.) responsible for the electrical engineering workforce education and training to scale the necessary skills and resources to build and operate these technologies on the grid
2	Coordination of EV Charging	• Continue to lead the charge on creating EV home charging and communication standards - including integration with utility DERMS systems, and universal communication standards for the home energy management ecosystem • Work with the vehicle manufacturers to provide greater assurances regarding battery degradation – for example to assure customers that using their EV battery to potentially provide residential flexibility / resilience will not invalidate the battery warranty • Collaborate with the electric utility ecosystem to ensure ubiquitous EV TOU rates across the country, establishment of V2G programs, and programs to install L2 / bidirectional home charging infrastructure to make new and existing homes EV ready
3	Deployment of Stationary Storage	• Work closely with the storage start up community and DOE to advance the commercialization of longer duration storage (4+ hours) to improve the effective load carrying capacity of the technology • Work closely with the software / platform technology industry (including perhaps distributed ledger firms operating in Europe) to create a direct utility to customer marketplace to animate consumer participation in storage programs • Convene with utilities and regulators to develop simple, clear, compelling commercial and residential storage-specific electricity tariffs to incentivize consumer and utility participation in storage programs
4	Deployment of Digital Substations	• Work with the utility regulator (maybe through a series of workshops) to educate them on the value of digital substations vs. new build and to ensure that as part of any utility rate case approval or substation development project approval, that a clear financial and operational rationale is provided for why digital substation investment is not appropriate • Work with the DOE to make funding available for these technologies more readily available and attractive to utilities and project developers • Work with entities (key universities and the IBEW etc.) responsible for the electrical engineering workforce education and training to scale the necessary skills and resources to build and operate these technologies on the grid

Source: PA Consulting 2024

The call to action – specific activities around the prioritized grid flexibility technologies that NEMA should pursue (continued)

	Flexibility Area	NEMA Actions
5	Optimization of Residential Appliance Usage	• Work with the construction industry to advance building codes and standards for new construction to favor electrification, energy efficiency and consumption-based flexibility • Continue to standardize communication protocols for energy assets and control technologies to make them easy to aggregate within the home / business, and eventually across homes and businesses • Collaborate with the utilities and regulators to advance more intelligent and automated demand management utility tariffs and programs to enable scale
6	Deployment of dynamic line rating technologies on the transmission grid	• Work with the utility regulator (maybe through a series of workshops) to a) educate them on the value of dynamic line rating vs. new build and b) to ensure that as part of any utility rate case approval or transmission development project approval, that a clear financial and operational rationale is provided to the regulator for why dynamic line rating technology is not appropriate • Work with the DOE to make funding available for these technologies more readily available and attractive to utilities and project developers • Work with entities (key universities and the IBEW etc.) responsible for the electrical engineering workforce education and training to scale the necessary skills and resources to build and operate these technologies on the grid
7	Optimization of Data Center Electricity Use	• Work with the data center industry and cooling technology companies to demonstrate that data centers can shift cooling load without compromising reliability, performance and down time of the data center facility • Work with utilities and regulators to put data center owners and operators on the hook for utility upgrade costs – thus financially incentivizing them to suppress demand during peak hours of electricity consumption upgrades • Collaborate with utilities and regulators to create utility tariffs and rates that are a sufficient to financially incentivize participation – particularly for short periods of extreme peaks
8	Continued deployment of AMI	• Work with utilities, AMI manufacturers and the smart home technology industry to understand how to use AMI to seamlessly connect smart electrical devices at home and work to the utility DERM's system – so economic use cases outside AMI infrastructure deployment and accurate meter reading can be commercialized • Work with utility regulators to advance real time (8760) electricity management, where AMI will play a critical role in measuring the hourly cost, reliability and cleanliness of the electricity homes and businesses consume – may also necessitate accelerated replacement of existing AMI technologies

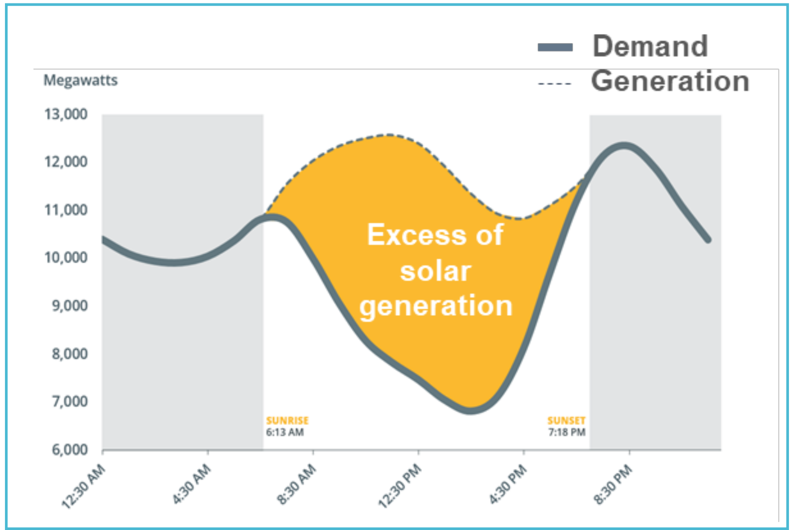
Source: PA Consulting 2024

Appendix i: Implications on the electricity grid of the future

- Shifting and spikier peak load episodes caused by electrification will challenge utilities in supplying reliable power
- Growing reliance on intermittent renewable power will also pose challenges to utilities working to balance demand and supply when renewable power is unavailable

Decarbonization of our electricity generation and growth in electricity consumption will present new challenges for matching supply and demand.

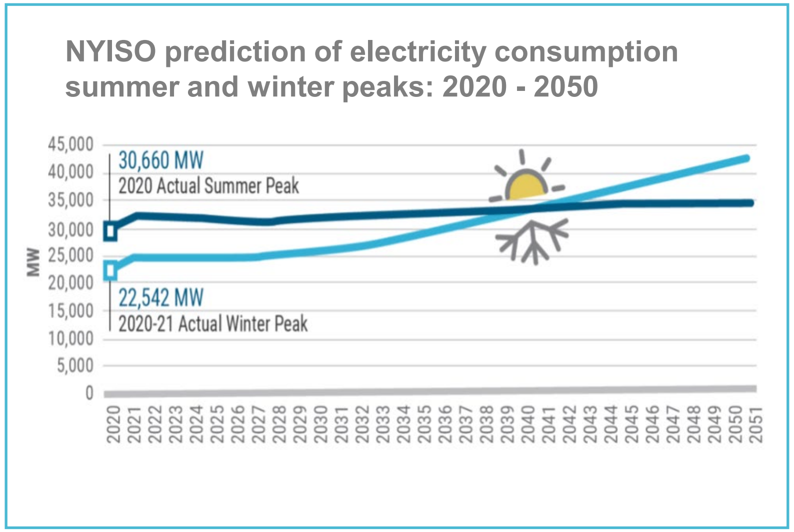
Over supply of intermittent & intractable sources of generation when it is not needed by customers



- Reduces load factor (economic efficiency) of generation
- Need to quickly ramp up other forms of electricity at sun set

ISO Newswire 2024

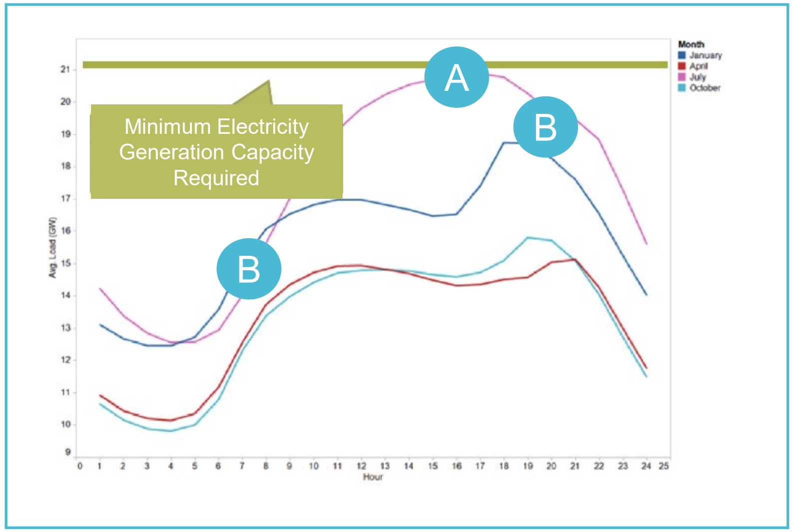
A shift in peak demand for electricity from summer to winter



- Renewables are typically more intermittent during winter months
- More importantly, demand for electricity (heating in particular) becomes more critical
- Importance of reliability and resilience

NYISO Gold Book 2022

Much peakier grid for short periods of time with sharper inclines and declines in consumption

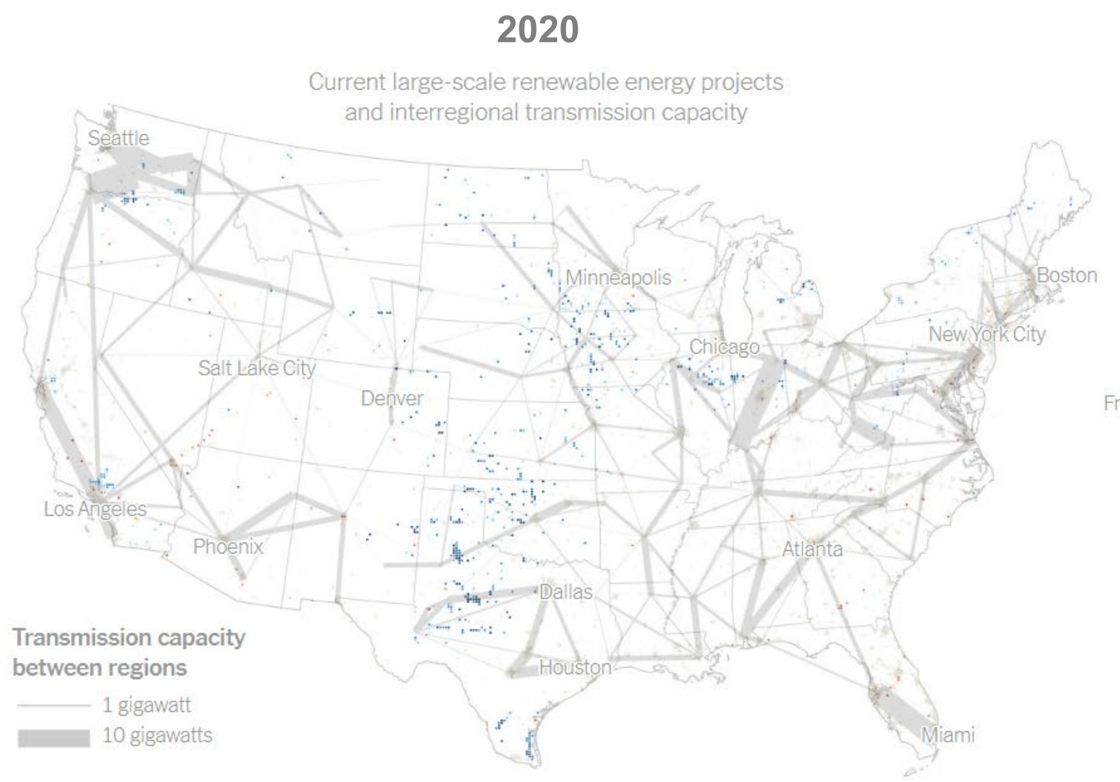


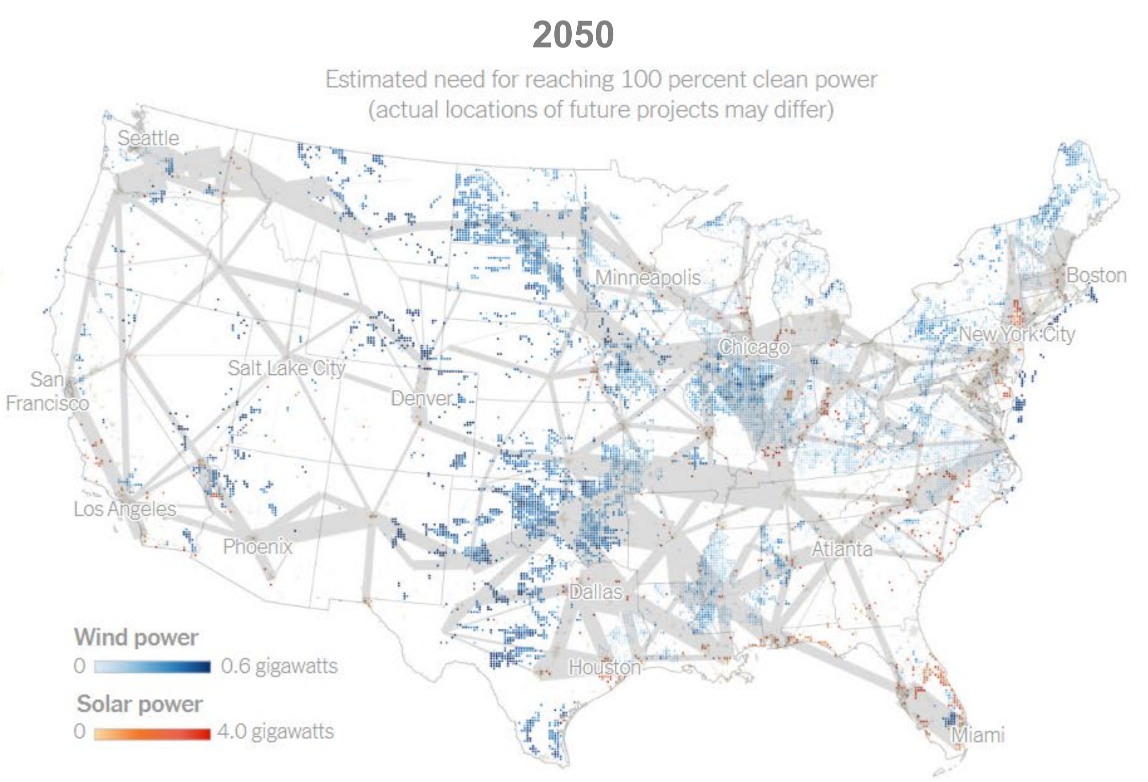
A - Building sufficient bulk generation capacity to cater for the super peaks (<100hrs per annum) may not be fiscally responsible
B - Generation and wires that can quickly ramp up and ramp down based on demand

EnergyCap Grid Fundamentals 2024

Left unchecked, these will have ramifications of reliability, affordability and the pace of both decarbonization of the power sector and electrification of our economy.

The US faces challenges to ensure that there is sufficient transmission to meet the changing composition of our power sector generation



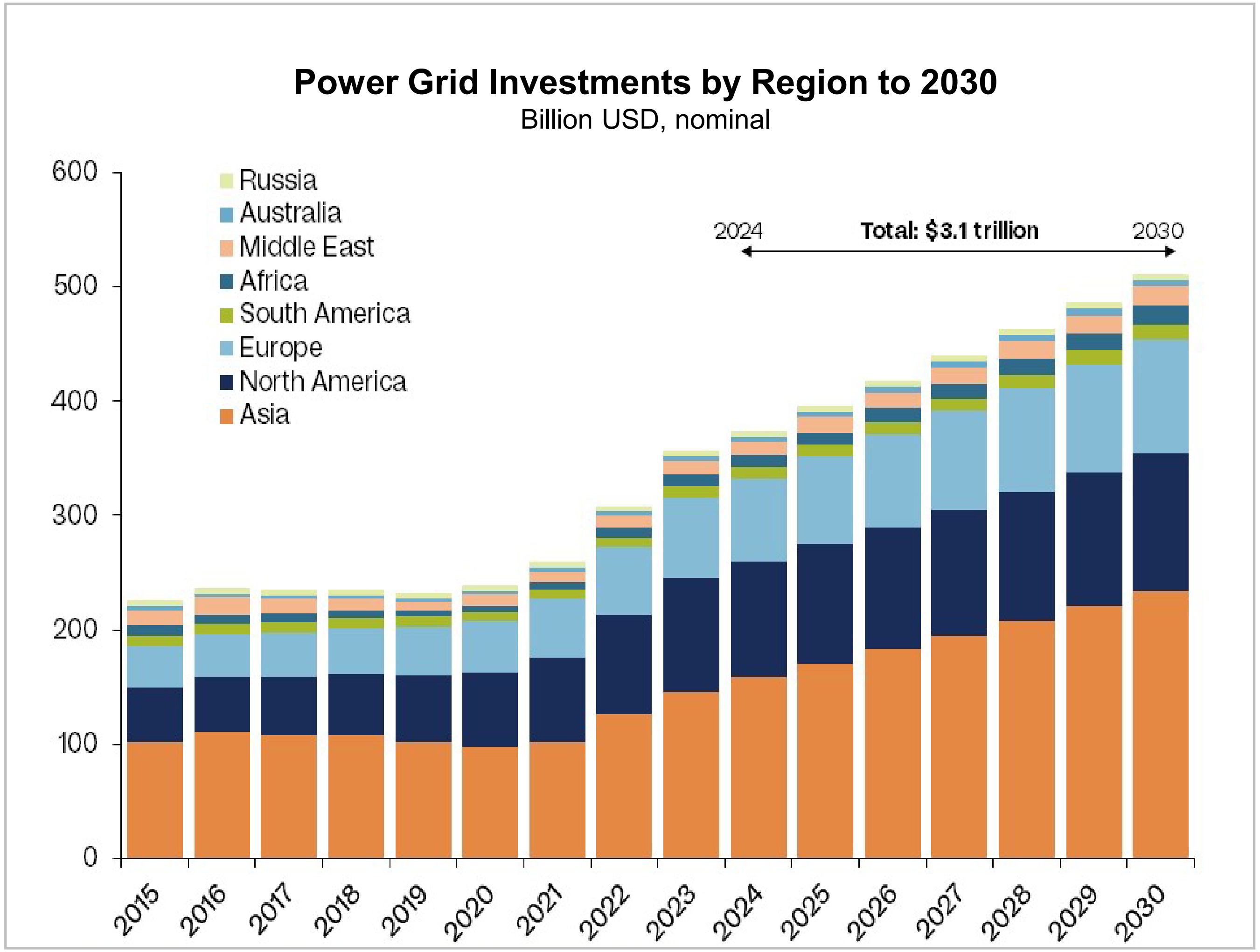


What is causing the need for new transmission:

- Due to ideal weather locations and larger physical space required, solar and wind located in places away from cities & where the existing grid is not
- Solar and wind typically generate less electrons per KW of capacity than the fossil plants they are replacing – in 2022 614 solar and wind plants replaced 166 fossil plants requiring greater number of connections
- Given intermittency and varying quality of solar and wind generation in different regions, the only cost-effective way to cleaning power sector is to share electricity generation across regional electricity grids – something that the current US grid can provide in a very limited fashion

Source: National Renewable Energy Laboratory | The 2035 map is based on the "All Options" path from NREL's 100% Clean Electricity by 2035 Study. Both maps show utility-scale renewable projects, but do not include distributed installations, like rooftop solar.

The US ideally needs to invest over $2.2* Trillion in the grid between now and 2050 to enable a decarbonized power sector – nearly four times a year more than is currently being invested



Implications:

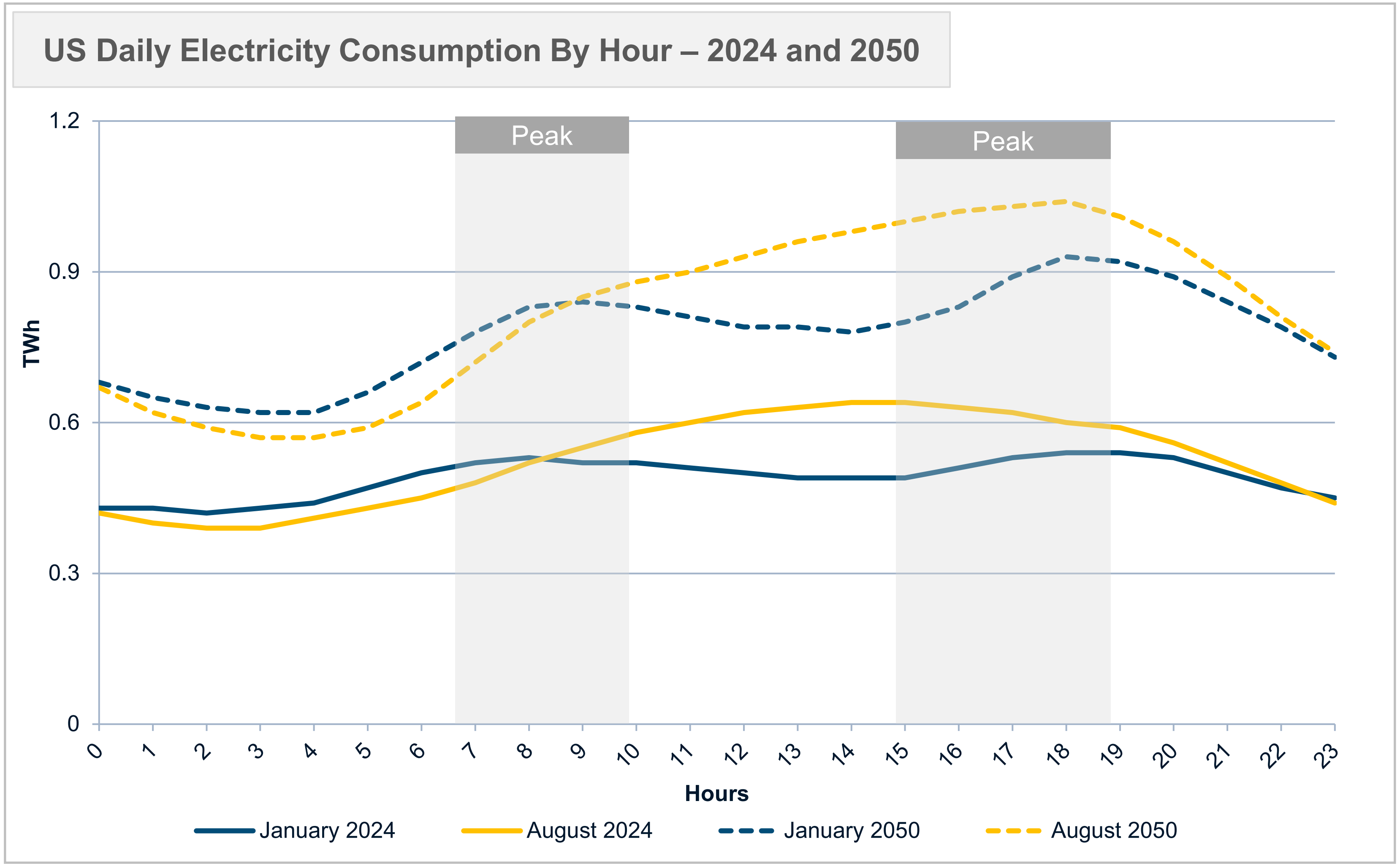
- Without building new transmission we will not meet expected US wide power sector decarbonization goals and electrification potential
- By end of 2022, 10,000 projects had applied for transmission interconnection
- Average interconnection times for projects have increased from 20 months in 2015 to 35 months in 2022
- Currently US utilities are spending about $25B a year on transmission projects, but this needs to rise to an average of $80B -$100B a year between now and 2030 to stay pace with projected renewables growth – costs that will be passed on to the consumer
- Yet, time to get permitting for new transmission projects can be as much as 17 years and amount of new transmission build / year has declined by 90% since 2015

Relying on transmission investments alone to both ensure we clean up our power grid by 2050 and connect that generation to the changes in electricity consumption in a reliable and cost-effective way is very risky

*equivalent of approximately $550 a year to the average electricity bill

Source: Rysted Energy research and analysis Feb

Not only is demand for electricity increasing but it is also creating greater seasonal peaks in consumption



Notes:

- NREL's forecast predicts an average increase in demand of 56% throughout the day, and up to 73% during evening peak hours
- Winter demand includes dual peaks in morning and evening, exceeding summer demand overnight due to electrified heating
- Peak demand is expected to shift later in the day due to electrification, and particularly in summer

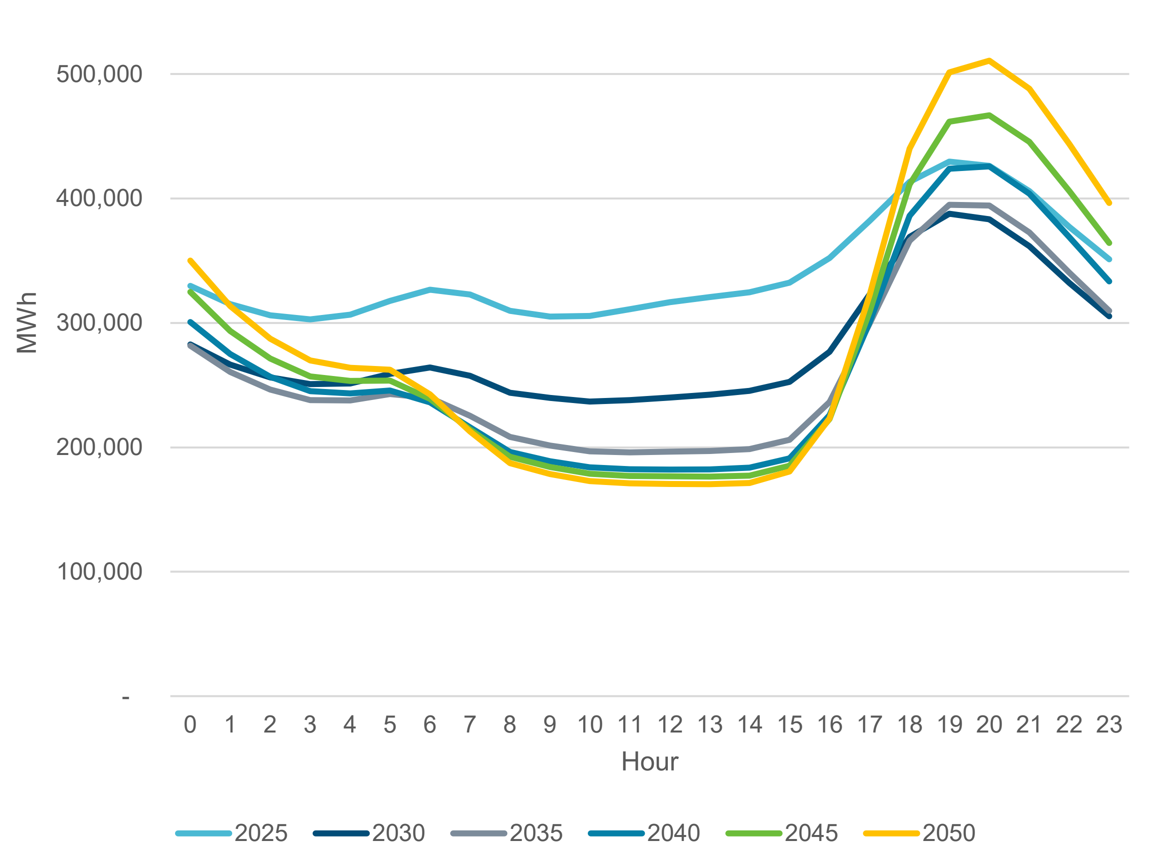
Implications:

- Peakier consumption equals more need for bulk supply, placing even greater pressure on the transmission and distribution grid to ensure that demand can be met with renewable generation
- Shift to a much higher peak in winter as a result of electrification of heating, particularly in Northern States, makes reliability and resilience of the grid even more critical when lives are at stake

Source: PA Consulting & NREL

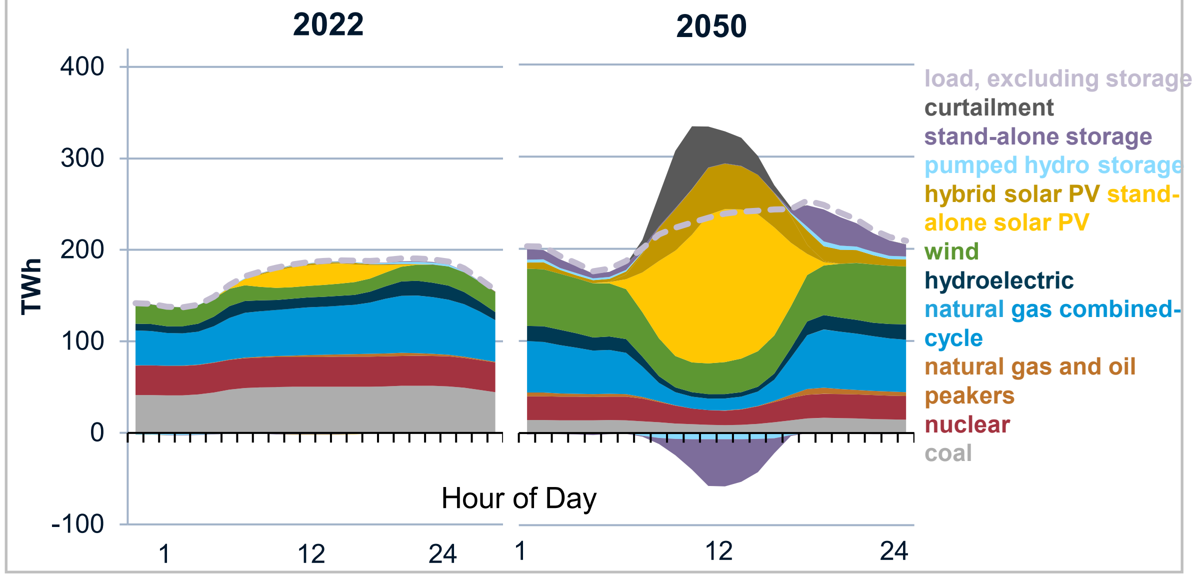
The shape of demand is also changing and will result in an increasingly steep afternoon peak ramp up in demand

US Hourly Net Average Electricity Consumption – 2025 to 2050



- Current system peak occurs around 2-3PM, though this is anticipated to shift later to 6PM.
- However, by 6pm, solar generation is dissipating, meaning that a significant net load will need to be met with other forms of generation
- The aggressiveness of increase in demand (150% increase across the entire system in 2 hours) is not something that the current US grid is set up to tackle
- Reliability and affordability issues

US Hourly Electricity Generation Mix By Source



Source: PA Consulting

Appendix ii: The role of grid flexibility in addressing the study's implications

- Why traditional utility approach to meeting growing demand by building more wires will not close the looming supply gap
- How technology upgrades to the grid can expand capacity to meet spiking peak power demand
- The significant positive effect of shifting behavior regarding when energy is consumed to improve load factor

In order to ensure that the electricity grid is positioned to meet growth in electricity consumption, the industry has traditionally looked to two solutions

Build sufficient generation and transmission capacity to meet even the peakiest day of electricity consumption

Each system operator regularly determines a level of generation and hosting capacity that is required to meet the peakiest day of demand without comprising grid stability and reliability in their region. This determines the minimum amount of generation and transmission capacity required.

Why it wont be enough to meet electricity consumption over the next 25 years:

- *More challenging to control when the system generates*: Over half the US generation capacity by 2040 will be solar and wind which is non dispatchable and cannot be turned on to meet peaks in demand
- *Cant build quickly enough:* It is projected that we will need to expand the US transmission system by 60% between now and 2050 to meet changes in generation and consumption, yet we have seen a downward trend in the build out of transmission over the last 20 years and construction times grow to an average 10 years (and in some cases 20 years)
- *Impact on local generation that doesn't need transmission:* Behind the meter solar is projected to meet only approximately 7.5% of additional electricity demand between now and 2050

Deploy energy efficiency solutions to suppress electricity consumption

Energy efficiency is driven by two interlinked disciplines:

- Improvements in energy consumption efficiency of technology
- Utility energy efficiency programs to incentivize participation

Over the last 25 years it has been credited for suppressing much of the organic growth in US electricity consumption

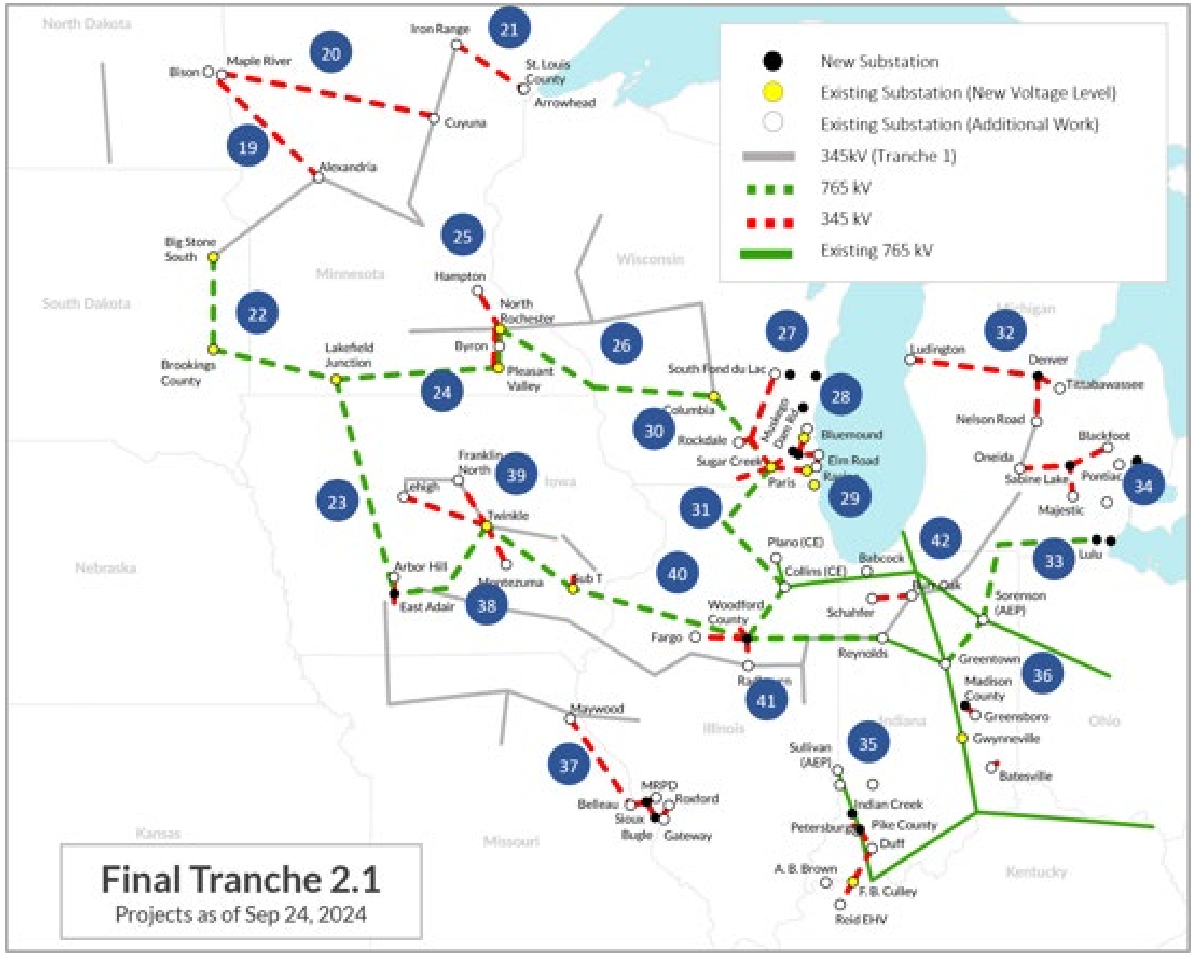
Why energy efficiency won't be enough to meet electricity consumption over the next 25 years:

- *Impact of continued energy efficiency efforts:* Energy efficiency is projected to suppress about 28% of additional electricity demand between now and 2050
- *Energy efficiency is contradictory to the traditional utility business model:* Utility spending on energy efficiency programs – a key indicator in determining the industries commitment to energy efficiency – is trending downwards Similarly, the impact of energy efficiency on peak demand is also lessening – shaving 0.7% of peak electricity consumption in 2023 vs 0.8% in 2022
- *Unpredictability in consumer participation:* While some of the increase in energy efficiency impact comes from technology advancements, most require consumers to participate (and pay) for improvements

These two solutions alone will unlikely be able to adequately address potential reliability and affordability challenges over the next ten years

Transmission is arguably the critical constraint that will prevent the bulk electricity grid from meeting projected increases in electricity consumption and decarbonization of the generation stack - particularly over the next 10 years

Focusing on the Mid-Continent Independent System Operators Long Range Transmission Plan for a moment



- The Mid-Continent Independent System Operator (MISO) is currently conducting a progressive long-range transmission planning effort – arguably placing them at the cutting edge of transmission planning in the US
- It is proposed that the region needs to implement 24 high voltage transmission projects over the next 10 years at a cost of $21.8B to:
  - Support high system transfers under generation and weather patterns
  - Resolve thermal and voltage violations throughout MISO's Midwest Subregion
  - Address congestion and reduce economic price separation
  - Enable significant new generation to support MISO member plans and goals
- Between now and 2040, the MISO is expecting 369GW of additional generation capacity to be built, 103GW of retirements, and electricity consumption to grow to 145GW during winter peak
- The plan now being socialized through a formal stakeholder review process and therefore nothing has yet been approved
- With only 55 new miles of high voltage transmission constructed in the US in 2023 , it is yet to be seen whether planned in service dates are achievable

Source: MISO & PA Consulting

Given potential timing and cost constraints of building new transmission and the practical limitations of energy efficiency, the electric utility industry has two other levers to keep pace with the projected changes in the US electricity system

The Electricity Supply and Consumption Equilibrium

Build more wires

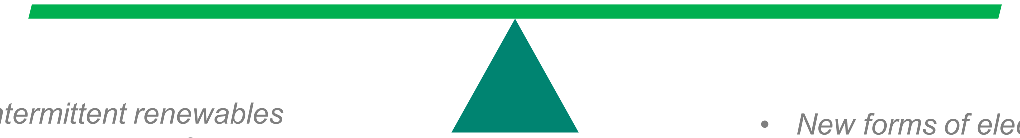
Energy Efficiency

A Do more with existing wires

Change electricity consumption behaviors B

Supply

Demand



- *Intermittent renewables with lower load factors*
- *Significant growth in number of generation assets*
- *Ageing transmission and distribution infrastructure*

- *New forms of electricity consumption*
- *Peakier, less predictable consumption*
- *Greater dependency on the electricity grid*

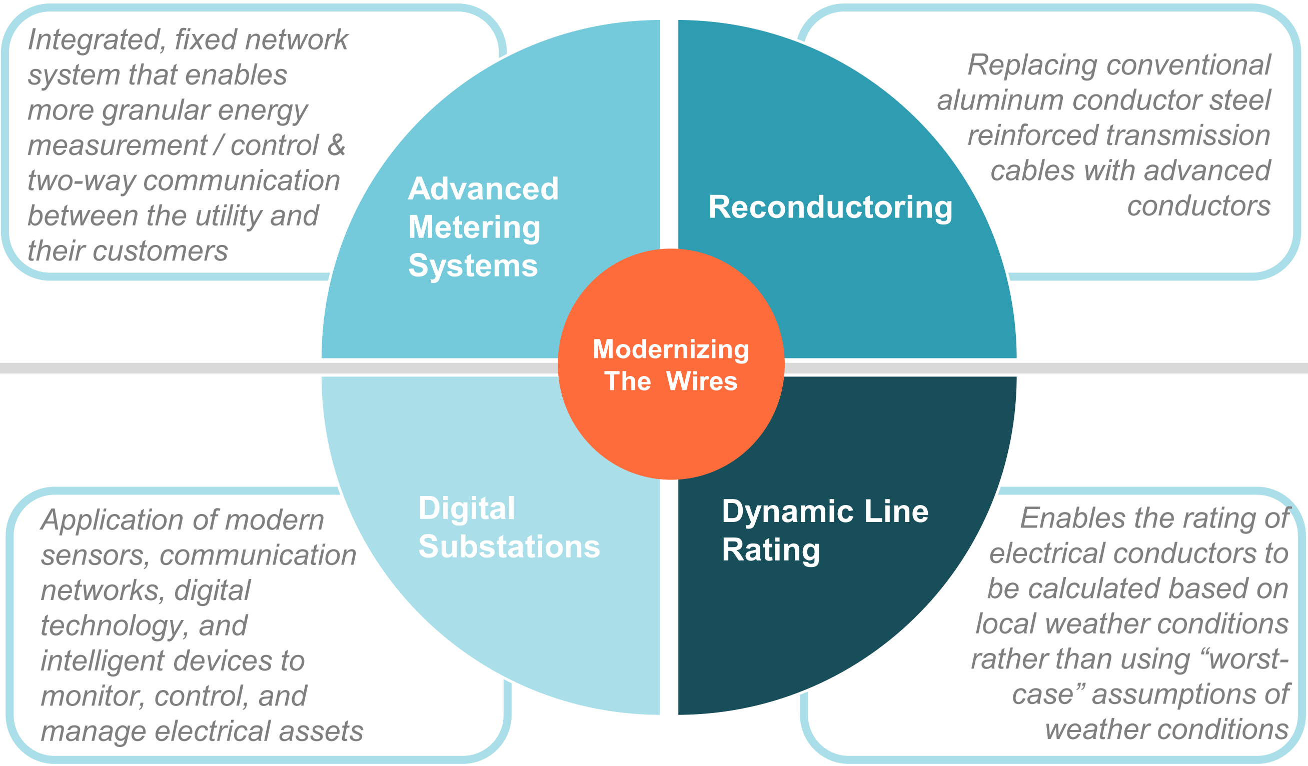
A Do more with what we already have: use technological advancements, data and AI to increase the potential capacity and resilience of our existing transmission and distribution system

B Focus on changing when, where and how humans consume electricity at times – particularly where the grid is under pressure to meet consumption

These alternative solutions are about creating a much more flexible electricity grid – one that can better respond to uncertainty & mismatches between supply and consumption – and if used correctly can be an incredibly cost-effective way to address both supply and consumption-based challenges

Doing more with our existing transmission and distribution grid assets – modernizing existing wires is critical to both unlocking renewable generation potential and enabling demand flexibility at scale

- Critical for enabling control of customer electricity consumption and utilization of behind the meter grid assets
- 130 million smart meters already installed (over. 80% of all bill payers)
- Projected 11.2% CAGR out to 2027



- Reconductoring transmission lines could add about 64 TW-miles of new interzonal transmission capacity by 2035 compared to about 16 TW-miles from only building new transmission line allowing the US to get 90% of its electricity from emissions-free power sources by 2035.

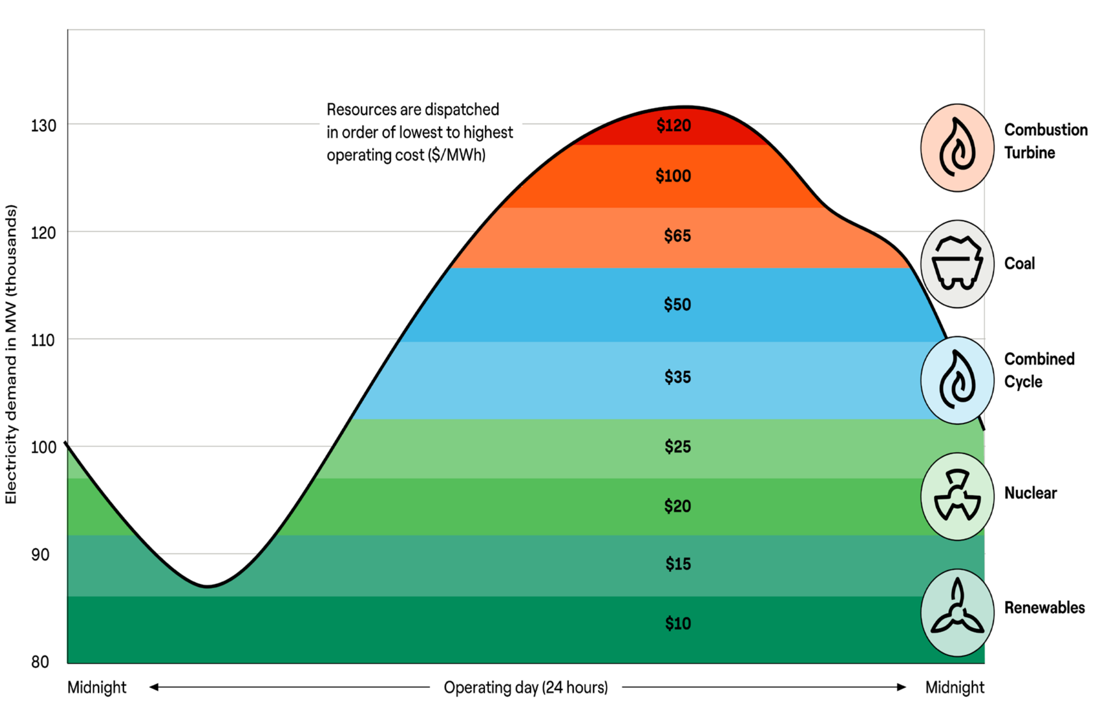
- North America Industrial Digital Substation Market was valued at USD 1.1 billion in 2023 and is projected to expand at a CAGR of 6.1% between 2024 and 2032
- Cost less to deploy than physical substations, safer, easier to maintain and provide granular access to real time data

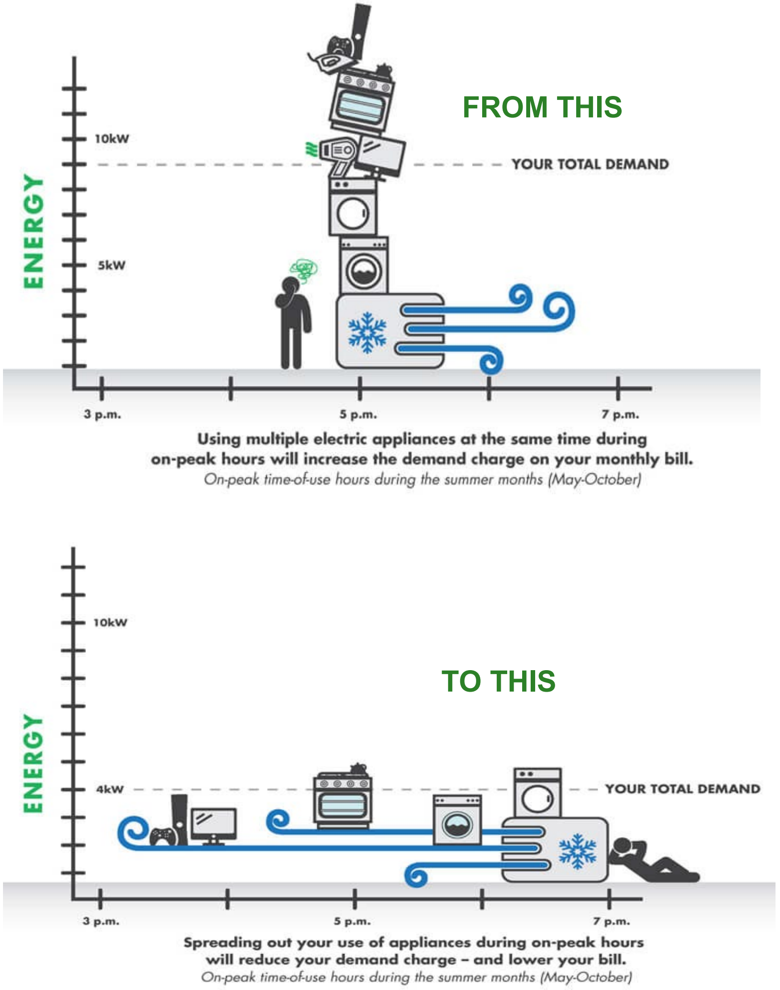
- Almost all lines will see at least 10% more capacity 90% of the time, and the average increase in capacity can be 30-50% with favorable climate and geography - addressing transmission constraints that cost ratepayers and generators over $20B/year
- Take only months to deploy vs. years for new build

Source: Various studies

Demand flexibility is the changing of electricity consumption patterns by reducing, shedding, shifting or modulating loads and is essential to the future of the electricity grid in several keyways

It enables electricity grid operators to move when electricity is consumed to times of the day that maximize the utilization of renewable generation – not only helping achieve power sector decarbonization goals but also utilizing lower cost generation resources more frequently



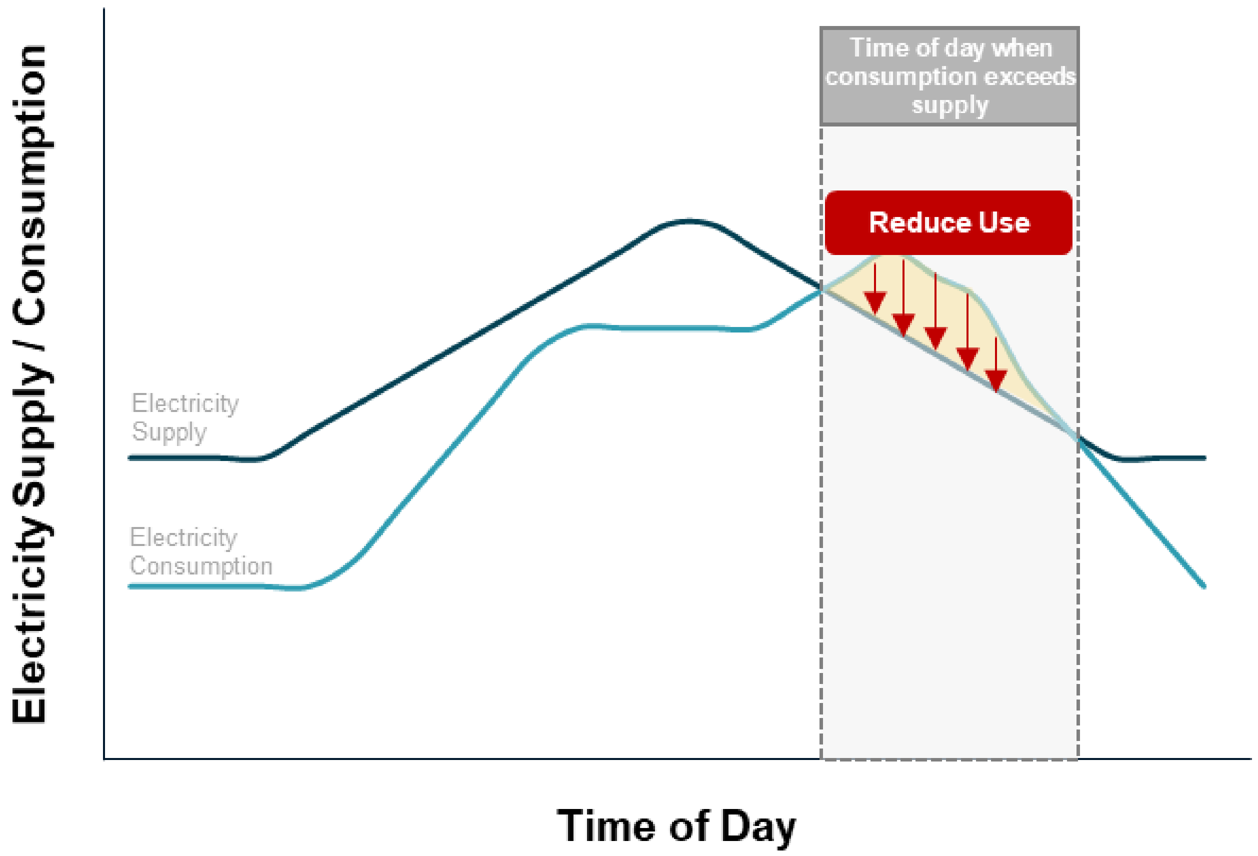


It is a much more responsive, cost effective and quicker to implement tool than building generation and wires in response to managing increasingly sharp peaks in consumption as well capacity and reliability challenges

Source: Unisource Energy Services

Consumption-based grid flexibility – temporary reduction in electricity use in response to lack of available supply, peaks in consumption and / or excessive price escalation

1 Temporarily Reduce Electricity Consumption



A Short term reduction in electricity consumption is already being deployed in many parts of the US through basic to more complex demand response programs

B In 2021, the United States registered 29 GW of peak demand savings potential across all its demand response programs. Over 10 million residential, commercial, and industrial customers were enrolled, resulting in total energy savings of 1154 GWh this year – roughly 0.02% of US electricity generation

C Typically, the way this type of grid flexibility works is by incentivizing customers to either actively participate in demand response events or to hand over control of their energy assets directly to an electric utility (or third-party aggregator) to control upon certain economic / physical grid conditions occurring.

D As customers are typically only being asked to turn down electricity use vs. turning off devices and assets, incentives have been proven to work effectively. Moreover, the technology to manage demand response automatically is already commercialized and the electrical assets they would manage are already in situ.

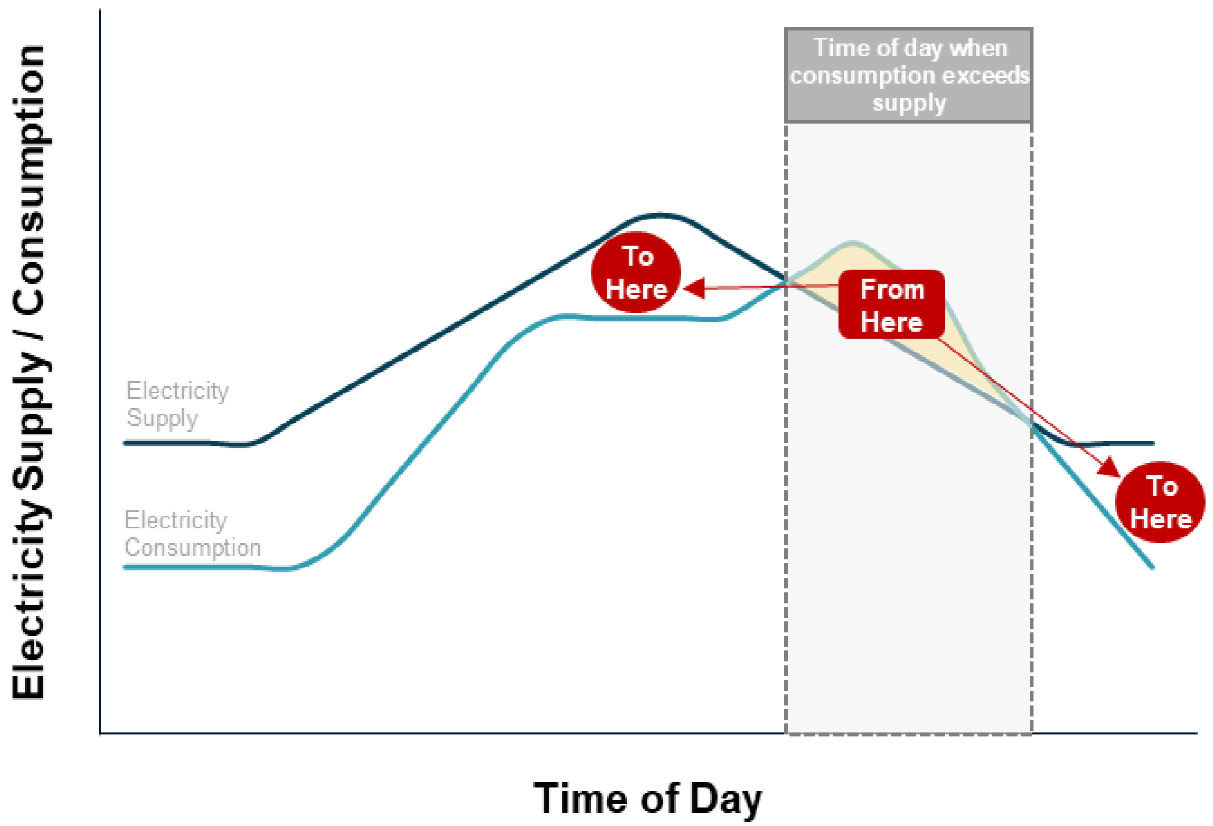
Areas of electricity consumption that will likely be best suited to this form of grid flexibility in the next 10 years:

- Heating – residential and commercial buildings
- Cooling – residential and commercial buildings
- Lighting – residential and commercial buildings

Source: PA Consulting

Consumption-based grid flexibility – shifting of electricity use away from peaks in demand and / or periods of low generation productivity to times in the day where renewable generation far exceeds typical demand

2 **Temporarily Shift Electricity Consumption**



A. This form of demand flexibility is focused on shifting when electricity consumed across a 24 hours period to times in the day when renewable electricity generation far exceeds typical consumption

B. Programs that enable periods of shifting electricity consumption are already being deployed across many utility territories in the US

C. As of end of 2022, according to EIA, 63% of U.S. electricity customers had a time of use rate plan available to them, but only 7.3% are enrolled

D. While there is a level of "perceived" inconvenience for the consumer to move when they consume electricity, plus a lack of adequate financial incentivization for the utility to encourage participation across its customer based, as more of our homes and businesses become electrified and smart, and utilities get better at providing economic incentives to consumers, we would expect this form of grid flexibility to become much more prominent than it is today

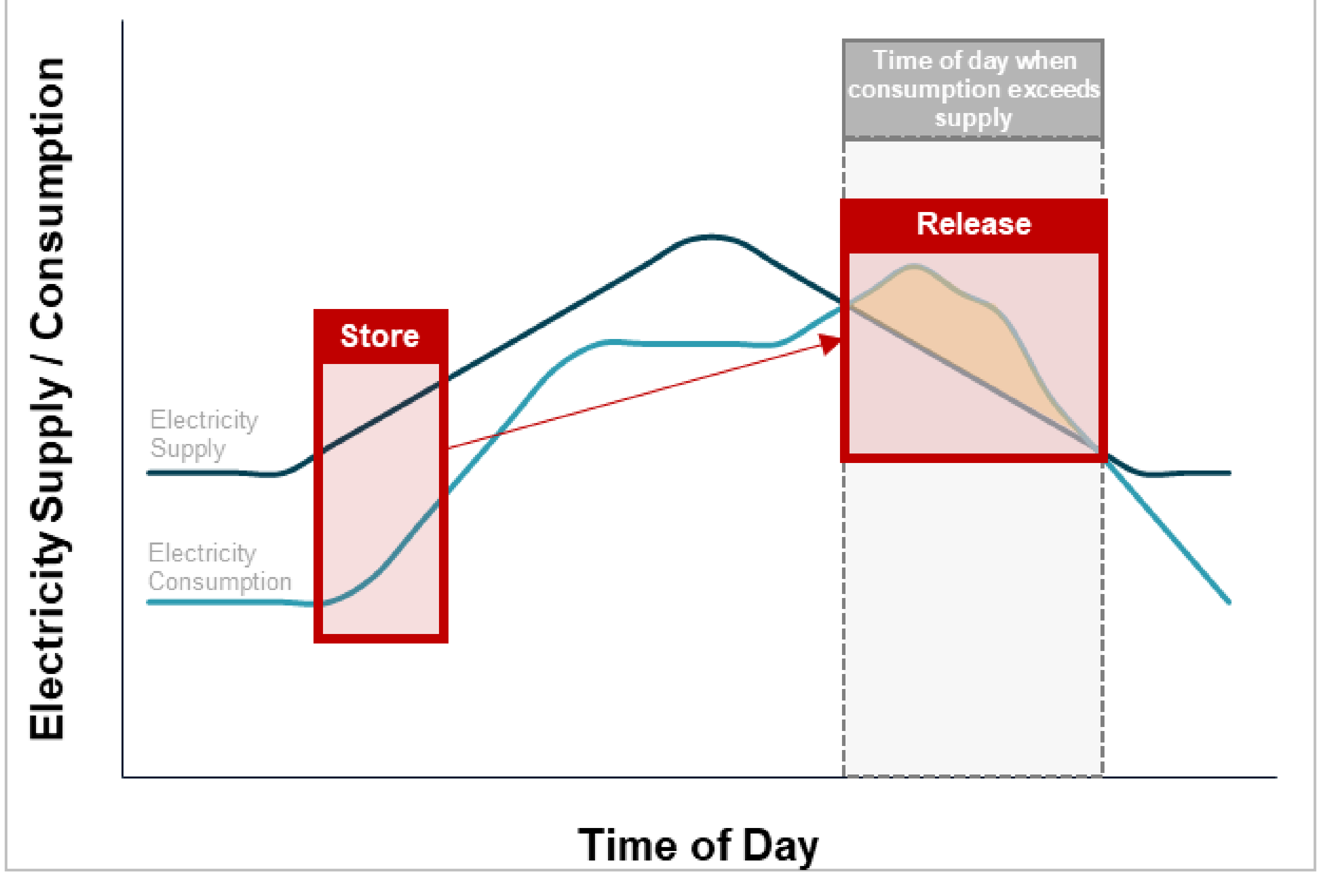
Areas of electricity consumption that will likely be best suited to this form of grid flexibility in the next 10 years:

- Electric vehicle charging
- Pre-cooling of data center load
- Smart management of home electrical assets such as washing machines and dryers

Source: PA Consulting

Consumption-based grid flexibility – storing electricity when renewable generation is prevalent and releasing that storage when the grid is under operational or financial duress

3 **Temporarily Store Electricity**



A — Storage is arguably the least mature consumption-based grid flexibility solution currently, despite over 17GW of grid scale and customer behind the meter capacity deployed in the US at end of 2023

B — It is expected that an additional 63GW of storage capacity will be added to the grid between now and end of 2027 that could be deployed to manage peaks, provide daily economic arbitrage and / or reliability related challenges

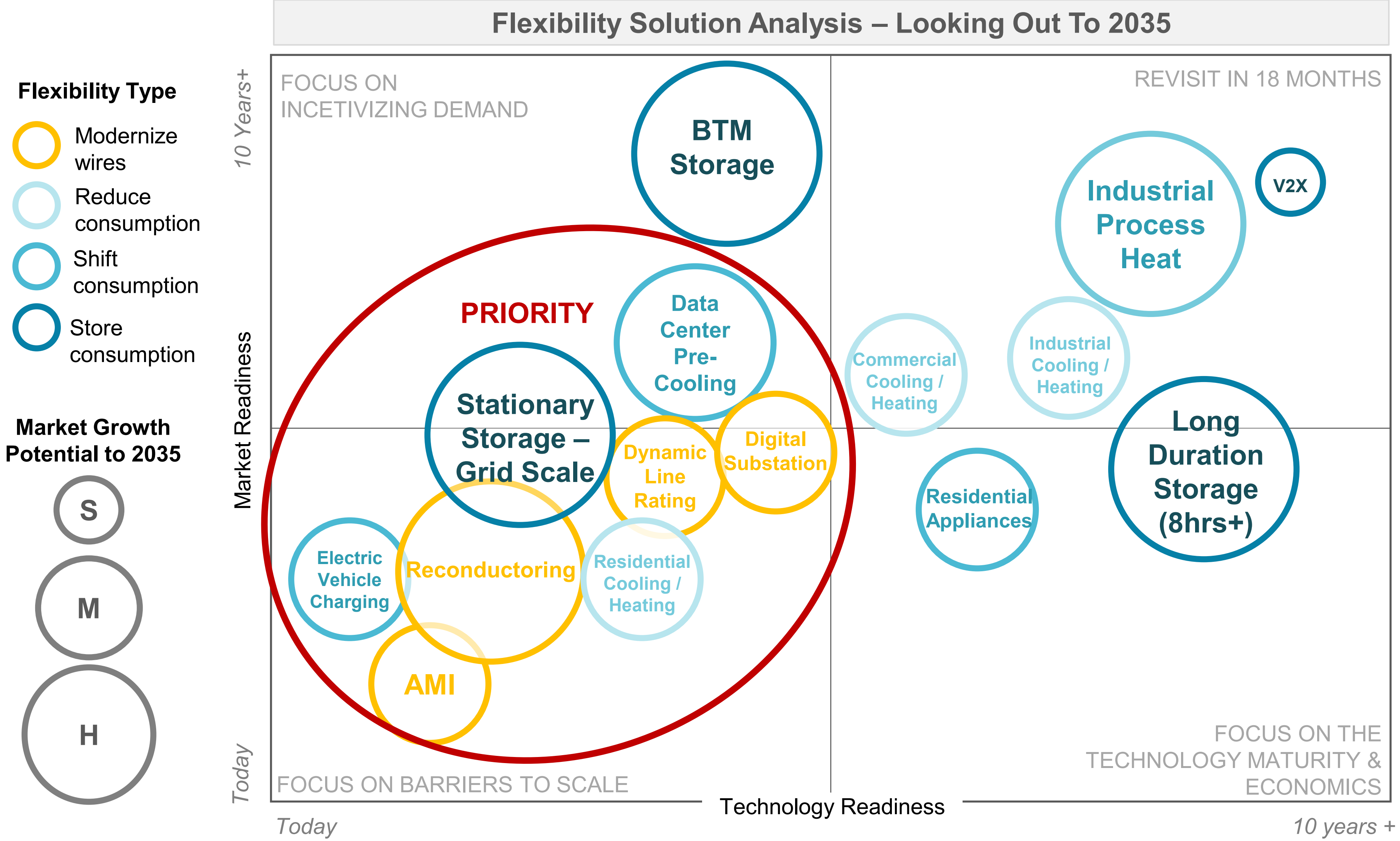
C — While the technologies to better utilize storage on the grid exist, utilities and regulators are yet to really push past pilot programs in their territories as they look to work out the necessary operational and financial use cases to scale deployment and value creation.

Areas of electricity consumption that will likely be best suited to this form of grid flexibility in the next 10 years:

- Stationary grid level storage – capacity and ancillary service focused
- Stationary behind the meter storage – capacity and energy arbitrage focused
- EV battery (mobile) storage – energy arbitrage focused

Source: PA Consulting

Between now and 2035, prioritizing areas of grid flexibility investment will be key to managing the changes in electricity supply and demand – ensuring continued reliable and cost-effective management of the electricity grid



Technology Readiness:

- Addresses the level of technology or solution maturity through the lens of to what extent the technology has been tested for operational feasibility, to what extent one off deployments have demonstrated financial and operational benefit and experience of deployment at scale

Market Readiness:

- Level of ease and financial incentive for customers to participate
- Level of utility desire to enable deployment of solutions in their territory
- Complexity of energy asset deployment
- Barriers to aggregate and scale

Market Growth Potential:

- Looks at supply and consumption projections
- Looks at published market CAGR's where applicable

Source: PA Consulting 2024

The following five areas of electricity consumption represent the clearest opportunity for scaling flexibility solutions in the next 5 years

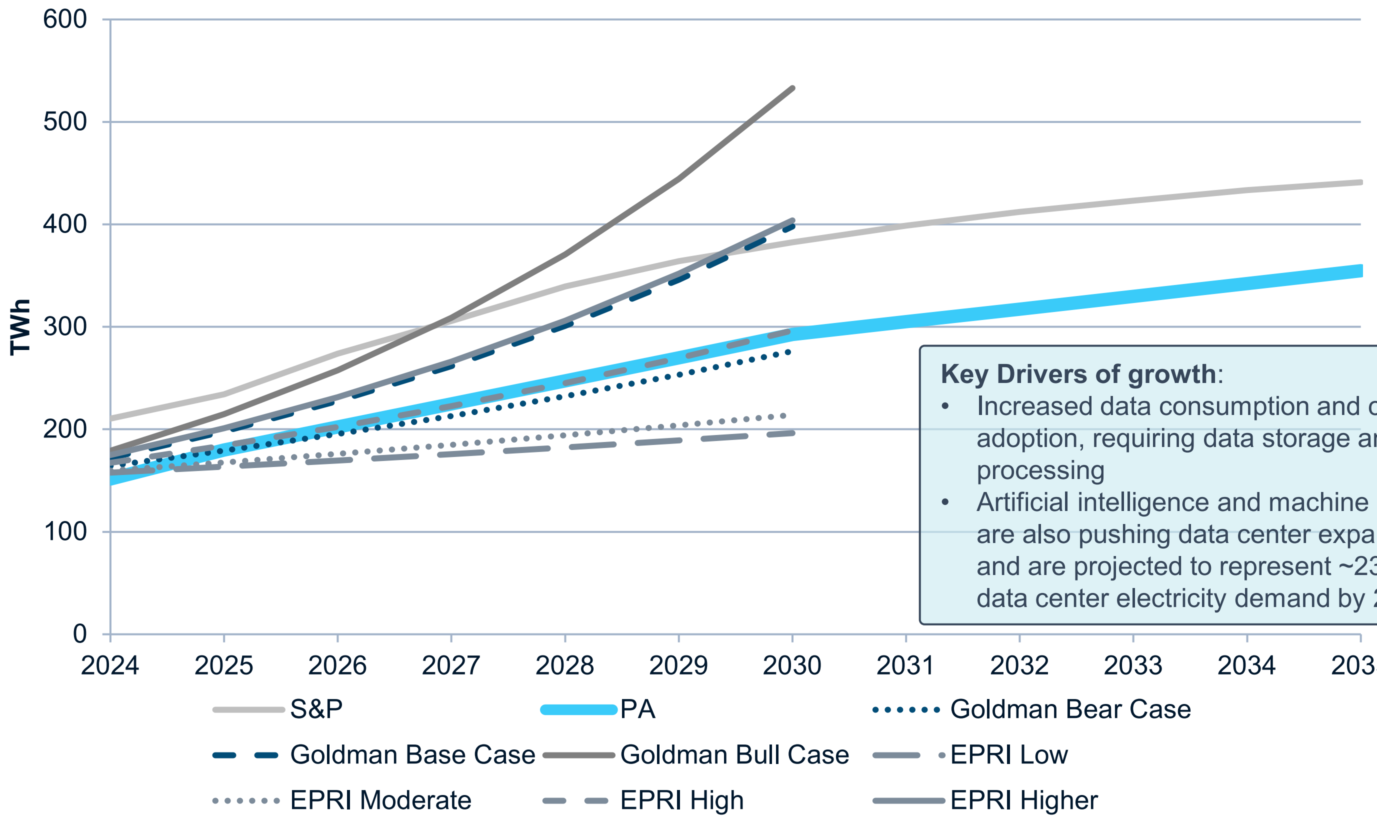
Grid Flexibility Consumption Area	
	Shift: Charging of electric vehicles – moving from peak to off peak hours
	Shift: Pre-cooling of non-essential data center functions to hours immediately before peak
	Reduce non-essential residential consumption at moments of peak or shift to nonpeak hours
	Store: Use of EV batteries as storage to meet short term inequalities in supply and demand
	Store: Customer stationary electricity storage assets for planned

Appendix iii: Deep dives on three major energy sector disrupters

- Data Centers
- Electric vehicle charging
- Energy storage

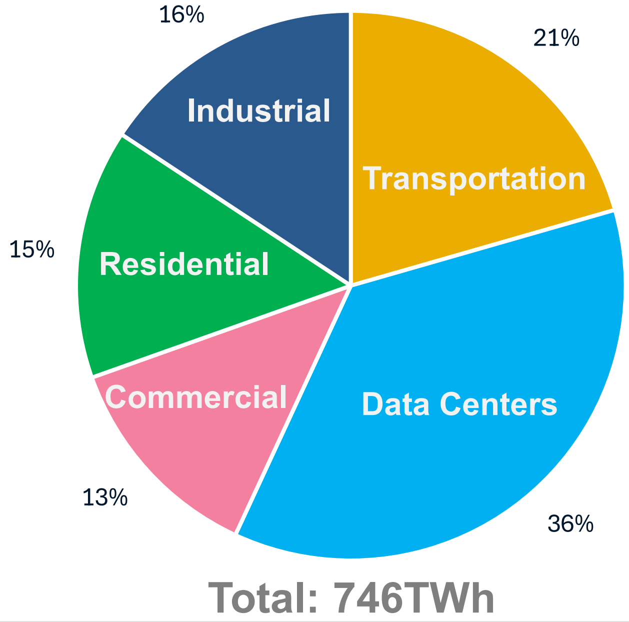
US data center electricity consumption is projected to more than triple in the next ten years and will, by far, be the largest contributor of electricity use growth across all segments during that period

Projected Data Center Electricity Consumption US: 2024-2035



Key Drivers of growth:
- Increased data consumption and cloud adoption, requiring data storage and processing
- Artificial intelligence and machine learning are also pushing data center expansion and are projected to represent ~23% of data center electricity demand by 2030

Consumption Growth By Segment: 2024-2035



- IEA estimates that in 2022, 3% of US electricity consumption was from data centers
- By 2030, data centers are expected to represent 8% of US electricity consumption
- In that same time period, generation capacity requirements will nearly quadruple to 76GW

Source: PA Consulting 2024

Data Centers

Electricity reliability is critical for the data center market and it will only become increasingly important as Tier 3 and Tier 4 drive much of new electricity consumption growth

Hyperscale Data Centers

- Massive facilities operated by tech giants like Google, Amazon, and Meta
- Designed to support cloud and big data storage at a large scale
- Customers: Primarily the companies that own them, supporting global services

Colocation Data Centers

- Facilities where companies can rent space for servers and equipment
- Highly scalable to meet changing needs
- Customers: Range from small businesses to large enterprises looking to outsource data center operations

Enterprise Data Centers

- Owned and operated by a single organization for their own IT needs
- Provides more control and customization for the organization
- Customers: Large corporations with specific and unique requirements

Cloud Data Centers

- Operated by major cloud providers like AWS, Microsoft Azure, Google Cloud
- Offer virtualized computing resources over the internet
- Customers: Companies of all sizes looking for on-demand computing resources

Edge Data Centers

- Smaller facilities located closer to end-users
- Reduce latency for applications requiring real-time processing
- Customers: Companies deploying IoT devices or requiring low-latency services

Tier 1

- Single non-redundant distribution path for power and cooling
- Estimated **99.6% availability** (28.8 hours downtime/year)
- Cost efficient but not very secure, unpopular in US

Tier 2

- Single distribution path for power and cooling with some N+1 redundancies
- Estimated **99.7% availability** (22 hours downtime/year)
- Slightly more secure than Tier 1, still infrequent

Tier 3

- Multiple power and cooling distribution paths, but only one active. N+1 redundancies for all components.
- Estimated **99.98% availability** (1.6 hours downtime / year)
- Good balance between reliability and cost efficiency, most popular tier

Tier 4

- Multiple active power and cooling distribution paths, 2N or 2N+1 redundancies.
- Estimated **99.995% availability** (26 minutes downtime/year)
- Highest reliability standard but expensive, second most preferred

Small DC	Average DC	Large DC	Hyperscale DC
100-150kW	1-5MW	~100MW	>100MW

Source: PA Consulting 2024

Data Centers

The growth in data center consumption will vary significantly from region to region driven by availability and cost of energy, network and fiber, water, land, and proximity to businesses

35% **Southeast**

Data center development largely driven by fiber network and renewable resources, as well as local tax incentives.

6% **Northwest**

Data center development largely driven by the need to be located near Silicon Valley and terminus of trans-Pacific fiber.

25% **Southwest**

Data center development largely driven by availability of land and renewable resources.

6% **Northeast**

Data center development largely driven by need for proximity to financial hubs. Land, water, capacity, and energy are limited and sparse.

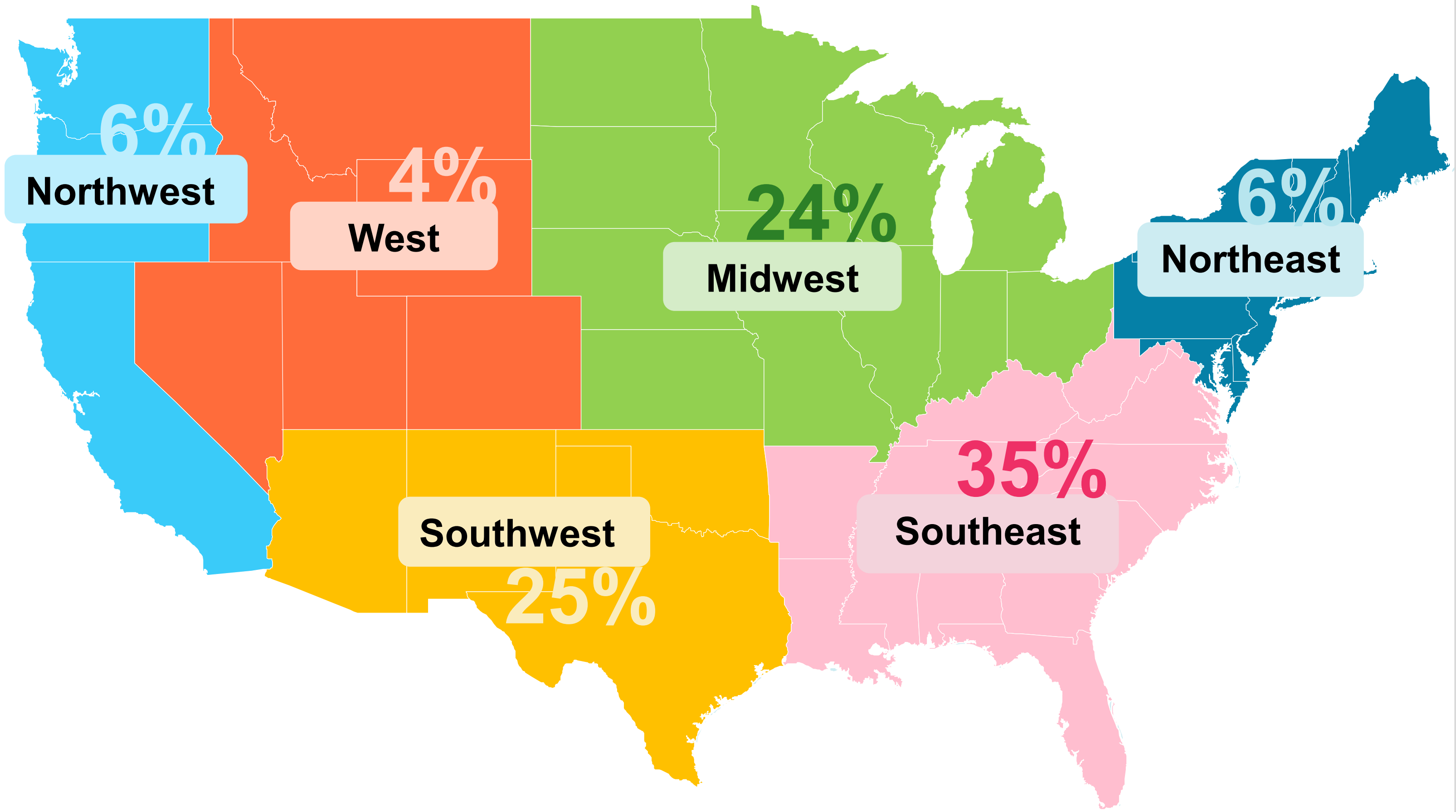
24% **Midwest**

Data center development largely driven by availability of land, water, and renewable resources.

4% **West**

Data center development largely driven by renewable resource potential as land, water, transmission, and capacity and energy are limited or remote.

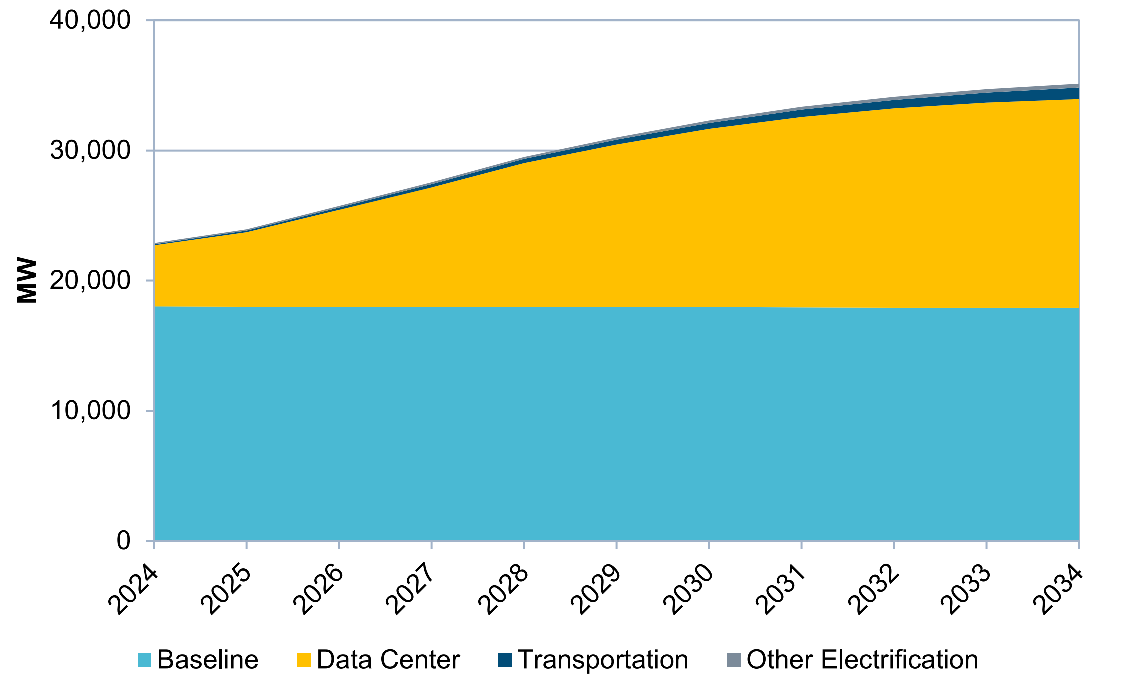
Projected Distribution Of Data Centers In The US to 2035



Source: PA Consulting 2024

And some locations, like Dominion's territory in Virginia, have unprecedented hyper-localized implications on the way the electricity grid is managed

Dominion Utility Territory Coincidental Summer Peak Demand Projections (MW)



Dominion serves over 2.7 million customers in Virginia and North Carolina. Dominion owns ~22GW of supply resources, with an additional 1GW in PPAs. Their current resource mix includes nearly 30% nuclear and over 40% natural gas. Dominion also anticipates over 1 million EV's to come online by 2034.

- Data centers accounted for **24% of electricity sales in Dominion's territory in 2023**, up from 21% in 2022.
- **By 2034, Dominion will have approximately 16 GW of data center load on their system**, nearly equivalent to the combined peak electricity demand of Minnesota and North Dakota.
- This will require significant grid capacity expansion:
  - Dominion's latest resource plan requests up to an additional **24 GW of solar capacity**, 9 GW of natural gas, **10 GW storage,** and 4.2 GW of small modular nuclear reactors.
  - To meet the expected demand in data center electricity consumption, the local system operator, PJM has **recommended about $4.9 billion in transmission projects** to help address reliability concerns related to new data centers and power plant retirements – with a focus on meeting immediate 2028 grid needs, but also to provide flexibility for future changes

Scaled demand side flexibility programs in Virginia and the Dominion territory could be an important testing ground for other geographic areas seeing similar trends

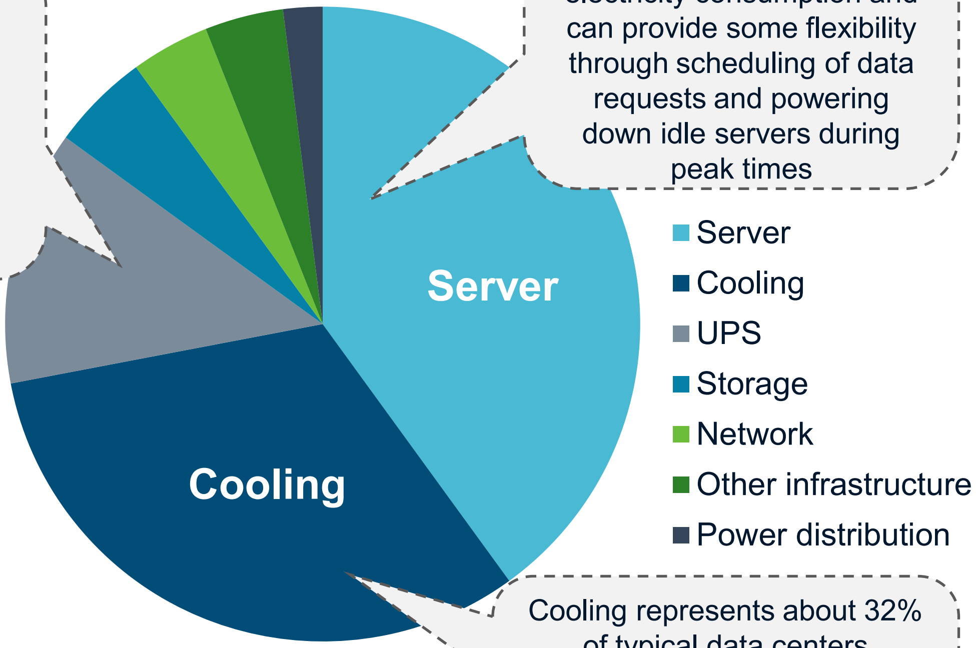
[1]MISO Loss of Load Expectation Study 2023-2024

With over 70% of electricity demand for data centers from servers and cooling, there is a significant opportunity deploy demand-based grid flexibility solutions – even small shifts in demand could have a big impact

Average Data Center Electricity Consumption By End Use

Uninterruptible power supply requires on-site backup sources, which could be used for **infrequent flexibility** services

Server consumption represents about 40% of a typical data centers electricity consumption and can provide some flexibility through scheduling of data requests and powering down idle servers during peak times



Cooling represents about 32% of typical data centers electricity consumption and is main opportunity for demand flexibility and continued efficiency improvements

Data Center Flexibility Opportunities

Utility Incentives: Utility rates will dictate possible savings and ideal grid flexibility procedures for data centers. Critical peak pricing can be a significant financial incentive for data centers to shift load.

Operating Temperatures: Broadening operating temperature limits to allow for greater application of precooling and cooling system cycling for grid flexibility purposes without disrupting operations.

Server Cycling: When possible, idle servers should be powered down, while maintaining a 'reserve margin' of always on servers. This process could be automated through power cycler software and synced to power price signals.

Data Request Scheduling: Non-time sensitive requests such as AI model training should be scheduled for off-peak hours.

Efficiency Gains: Ongoing efficiency improvements and adoption in cooling, server, and other associated technologies can be promoted through increased efficiency code stringency. This can also reduce electric system upgrades.

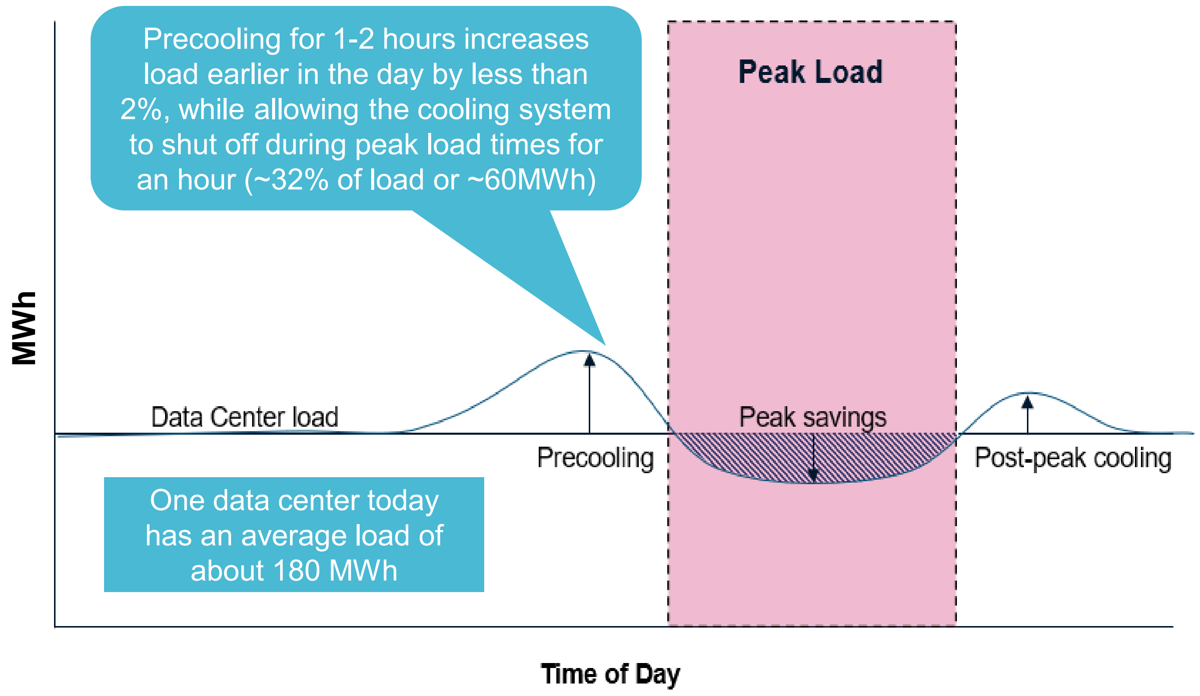
Source: PA Consulting 2024

The simplest way to demonstrate the value of demand flexibility would be through the automated shifting of small amounts of data center electricity consumption to different hours of the day

Load Shifting Considerations

- Avoiding peak load or ramping periods can provide daily grid balancing services (energy arbitrage) and serve as an alternative to some grid upgrades. This service can be compensated by the utility through time of use or demand response rate schedules.
  - This could include responding to weather patterns or taking advantage of excess solar during the day and wind at night
- Precooling the data center before a summer afternoon, for example, can shift load out of peak times without impacting data center performance.
  - Operators can allow temperatures in the data center to fluctuate within acceptable operating limits: lower during pre- and post-peak cooling, and higher temperatures during peak load periods.
- Many utilities deploy variable or time of use rates to motivate customers to perform this shift themselves.
  - Time of use rates tend to be higher first thing in the morning and/or afternoon/evening peaks, not including seasonal variances.
  - Data center siting considerations could include this time of use rates to estimate potential savings from flexibility services

Illustrative Daily Load Shifting of a typical sized (180MWh) data center



Source: PA Consulting 2024

Quantifying the opportunity – a standard sized data center in Dominion's utility territory could save over $600k a year in energy costs by simply shifting a manageable amount of cooling load away from peak hours

Dominion's Current Variable Pricing Large General Service Rate

a. For the period May 1 through September 30:

Day Classification	On-Peak Period	On-Peak Rate Per ES kWh	Off-Peak Rate Per ES kWh
A	2 p.m. – 7 p.m.	24.2487¢	5.8807¢
B	11 a.m.- 9 p.m.	2.0910¢	0.4875¢
C	7 a.m.- 10 p.m.	1.0378¢	0.2730¢

b. For the period October 1 through April 30:

Day Classification	On-Peak Period	On-Peak Rate Per ES kWh	Off-Peak Rate Per ES kWh
A	6 a.m.- noon & 5 p.m.- 9 p.m.	24.2487¢	6.8488¢
B	6 a.m.-noon & 5 p.m.- 9 p.m.	2.0910¢	1.0607¢
C	6 a.m.-noon & 5 p.m.- 9 p.m.	1.6951¢	1.0254¢

2023 Occurrence by Day Classification

A	25
B	271
C	69

- Given their steady load profile, data centers will have a difficult time reducing demand charges, which are set based on the highest demand in a 30-minute period from the previous year.
- Instead, leveraging **variable time of use rates**, data centers can save money by shifting load to less expensive times
- Dominion's Large General Service rate includes variable pricing for on and off-peak times, seasons, as well as a classification system for more critical days
- Classification A includes a much higher spread between on and off-peak prices, leading to the greatest share of potential financial savings
- An average data center in Virginia under Dominion's Large General Service rate, operating at a 90% load factor, has a demand of 180MW during a standard hour of operation.
- In a typical year, a data center would spend approximately **$32.5M in generation charges**

- Shifting **~6% of cooling load** (reducing demand 3.6MW each hour) from on-peak to off-peak times would save an estimated 0.78% of generation charges, or **$254,000 a year**
- Shifting **~ 15% of cooling load** (reducing demand 9MW each hour) from on-peak to off-peak times would save an estimated 1.97% of generation charges, or **$635,000 a year**

Source: PA Consulting 2024

With forecasts projecting that EV electricity demand in the US will represent nearly 3% of total US demand by 2030, up from a baseline of less than 1% today, it provides an immediate opportunity to demonstrate grid flexibility

GROWTH OUTLOOK

PA forecasts ~55M light-duty electric vehicles (LDVs) by 2035

- Projections from NREL, BNEF, and IEA are all in similar ranges

Demand requirements from exponential EV growth achievable as current baseline is low

- EV power demand is on a steep growth trajectory with CAGR projections of ~40% between 2023 and 2030, albeit from a low baseline

Long-term exponential growth

- Due to long stock turnover timelines, the majority of EV growth by 2050 will occur post-2035s

Growth uncertainty from potential state policy, technology changes

- State policies could change (e.g. reduce ambition), while technology (battery chemistry, vehicle autonomy) improvements could rapidly increase adoption

KEY DRIVERS

Transportation Decarbonization Policy

- States comprising >30% of new car sales have adopted California's ZEV regulations

Battery chemistry

- Lithium-ion battery costs have declined by >80% since 2013, and are projected to keep declining due to improvements in battery energy density

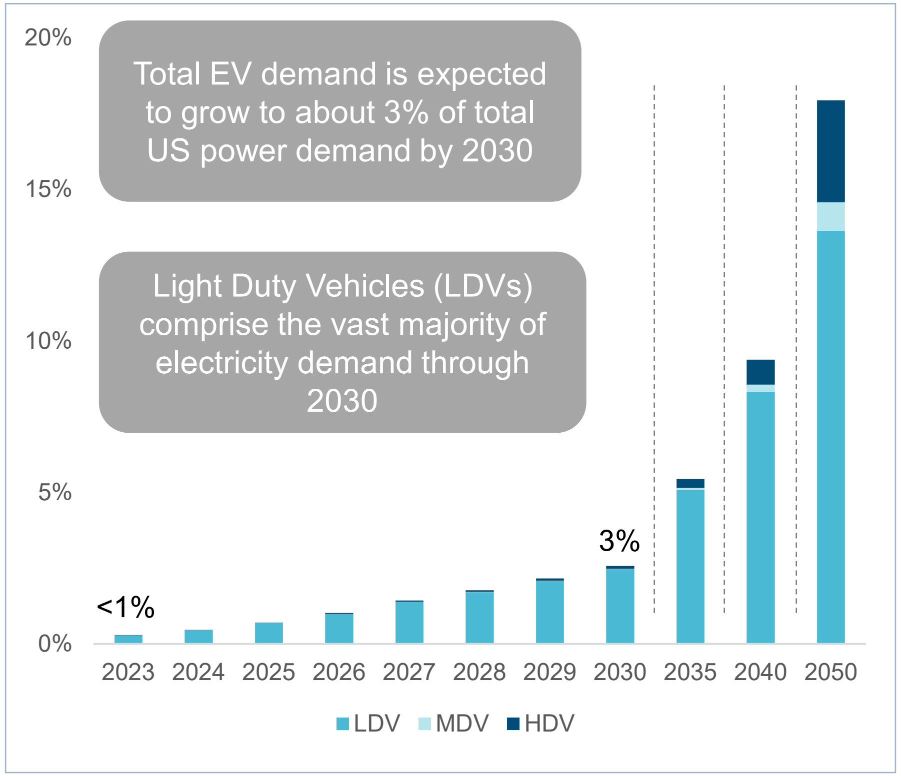
Climate and Geography

- Favorable weather conditions (e.g. mild winters), short driving needs, and high single-family home share (with garage access) are significant influencers into EV purchasing decisions.

Increased public charging access

- Federal/state programs (e.g. NEVI, state make-ready programs) are leading to significant public charging infrastructure improvements across all states

EV Share of US Electricity Demand



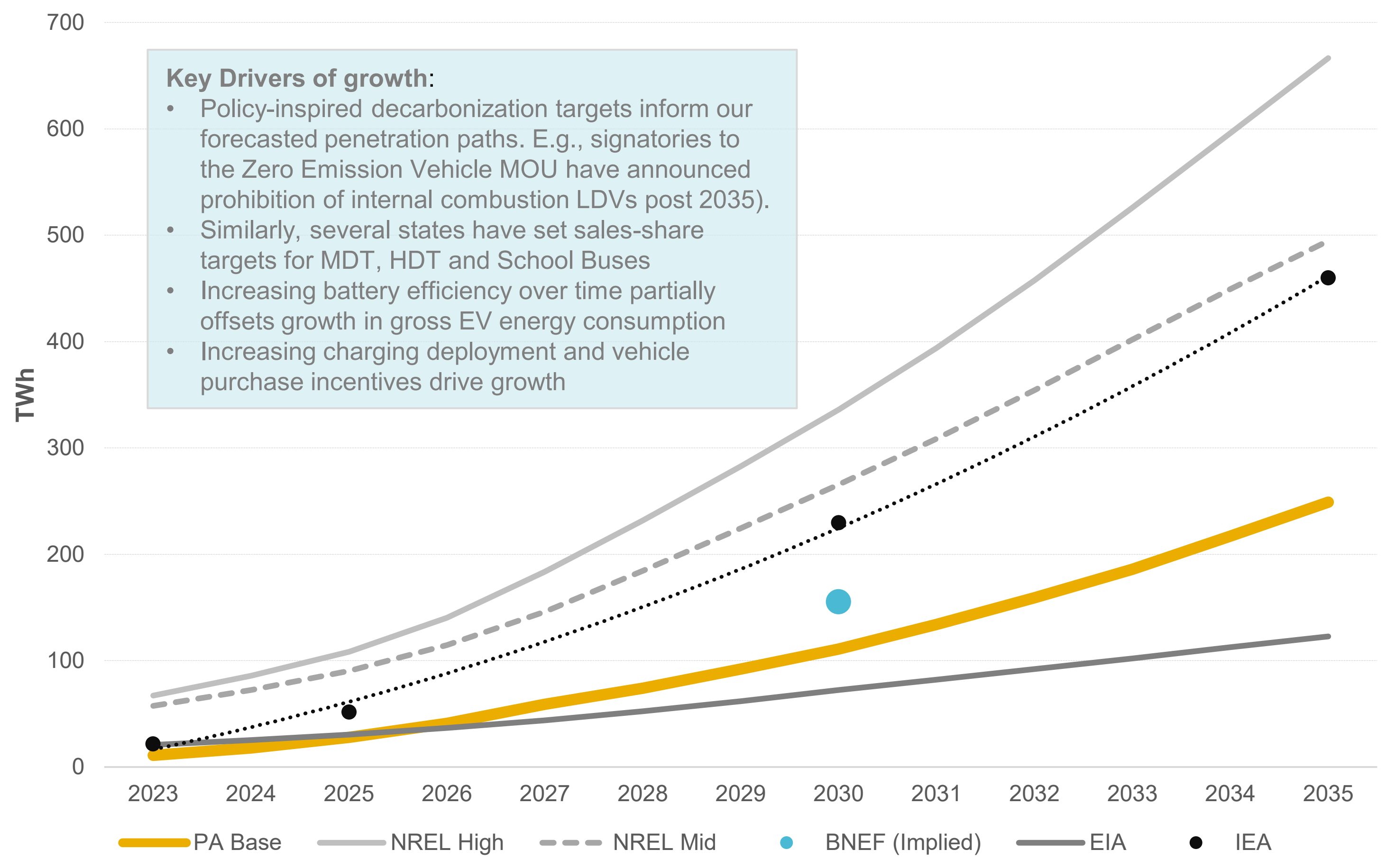
Demand from Medium- and Heavy-Duty Vehicles (MDVs, HDVs) will become a greater share of electricity demand beyond 2030, as electrification in those sectors increases.

Source: PA Consulting 2024

Electric Vehicles

Projections for EV adoption vary, and PA's base case remains fairly conservative. Yet we are still projecting a 10-fold increase in EV's on the road by 2030 – resulting in the second largest area of electrification growth in the US economy out to 2035

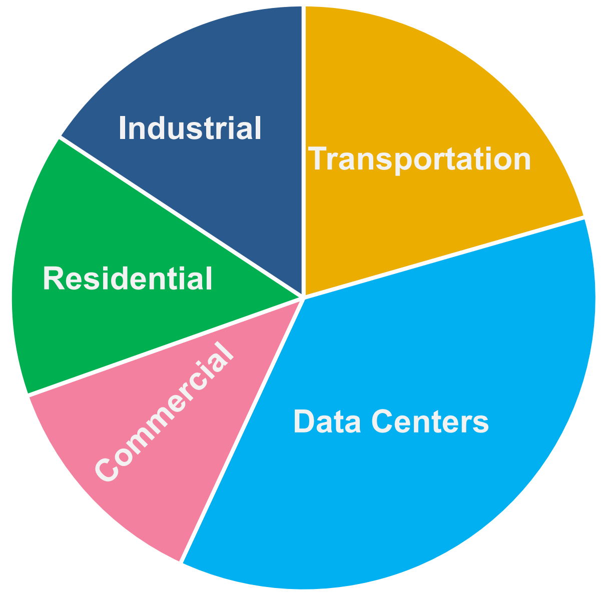
Projected EV Electricity Consumption US: 2024-2035



Key Drivers of growth:

- Policy-inspired decarbonization targets inform our forecasted penetration paths. E.g., signatories to the Zero Emission Vehicle MOU have announced prohibition of internal combustion LDVs post 2035).
- Similarly, several states have set sales-share targets for MDT, HDT and School Buses
- Increasing battery efficiency over time partially offsets growth in gross EV energy consumption
- Increasing charging deployment and vehicle purchase incentives drive growth

Consumption Growth By Segment: 2024-2035



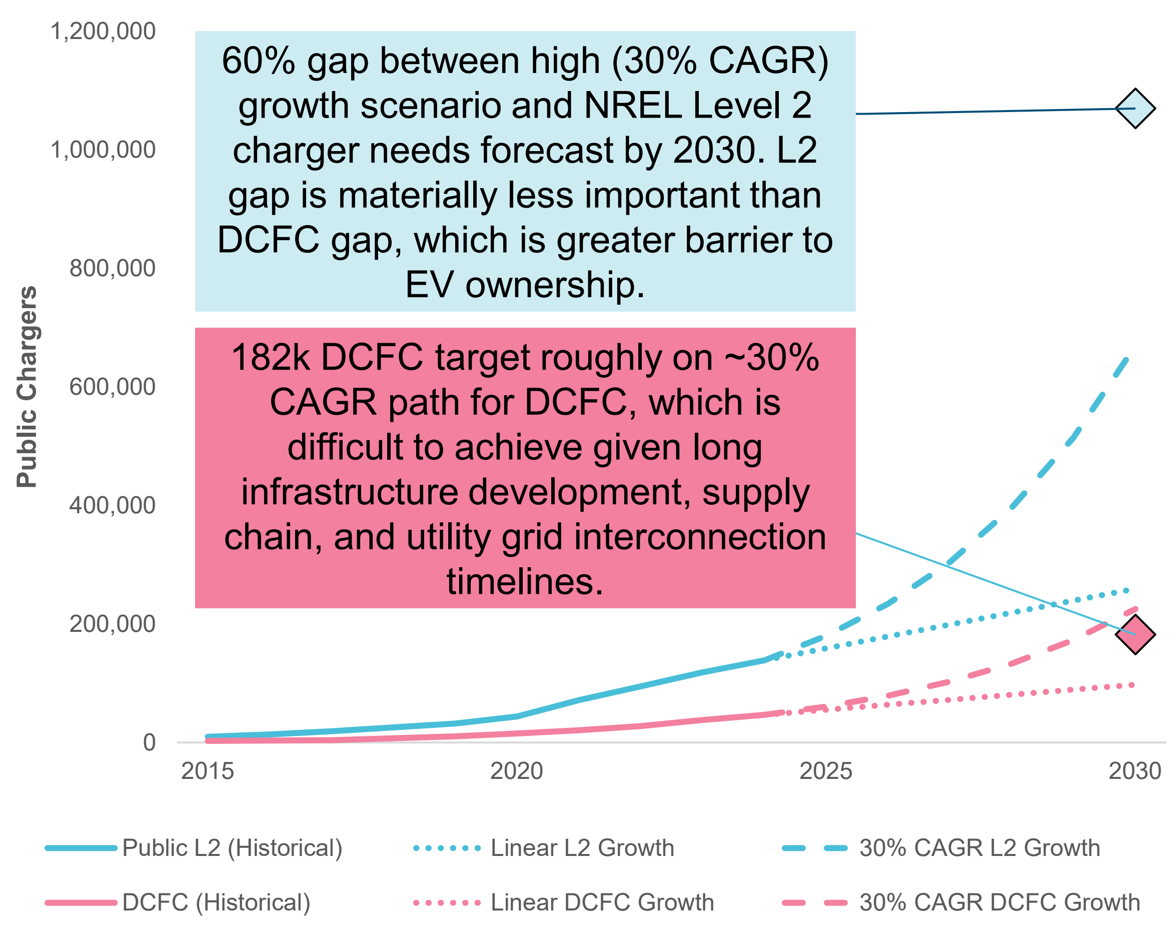
Total: 746 TWh

- IEA estimates that in 2023 less than 1% of electricity consumption in the US was from EV's
- By 2030, this is expected to rise to approximately 3%, 5% by 2035, and 18% by 2050
- By 2030 it is projected that there will be ~30M EV's on US roads, a ~10-fold increase compared to approximately ~3M in 2023.

Source: PA Consulting 2024

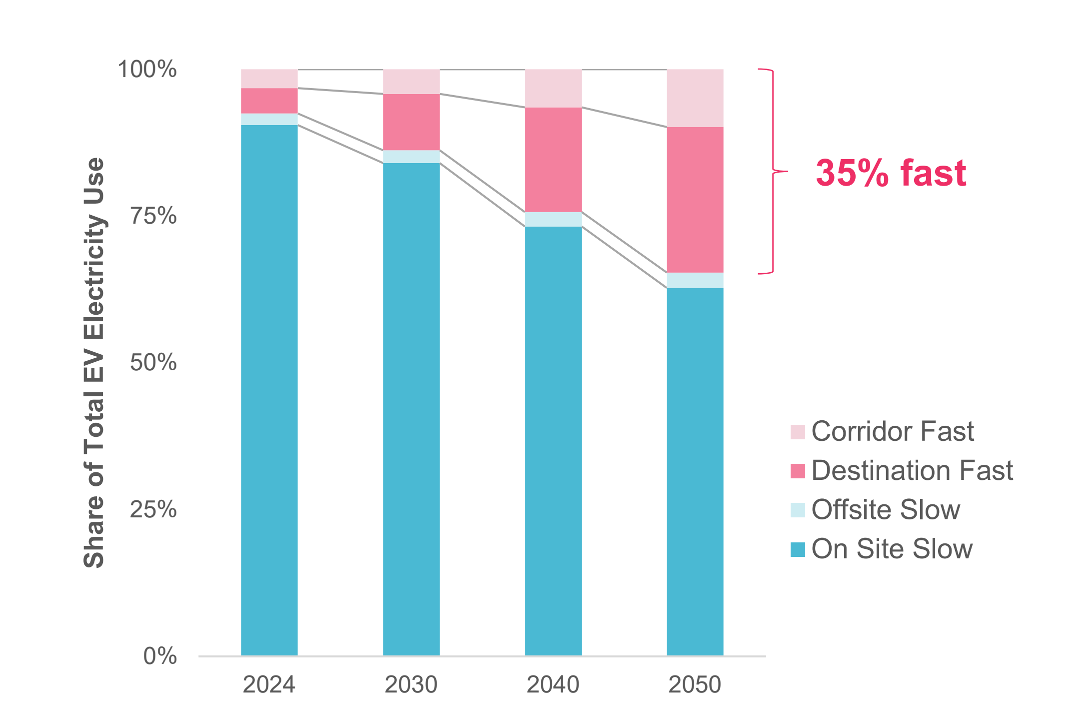
The public charging ecosystem not keeping pace with EV adoption remains the greatest barrier to achieving projected levels of vehicle electrification in the US – yet the overwhelming majority of charging will continue to occur at work or at home

Public L2 and DCFC Historical / Projected Growth and Needs



~1M public L2, ~200k DCFC are needed by 2030 to enable the next phases of growth in the EV market; DCFC are both harder to build, more critical for the next wave of EV adopters, which increase fast charging to 35% of total EV energy use

Charging Use Case Breakouts over Time



Source: DOE, PA Internal Modeling

The growth in EV electricity consumption will vary significantly from region to region driven by mostly by state-level EV regulations, as well as climate, geography, and customer sustainability preferences.

18%

Southeast

EV demand is relatively evenly dispersed (FL, GA, and NC are the main drivers), with favorable climate and high single-family home access.

36%

Northwest

EV load is the largest in this region, driven almost entirely by California's aggressive EV policies

11%

Southwest

TX and AR drive nearly all EV demand growth, driven less by state policy and more by customer preferences and favorable climate.

18%

Northeast

EV adoption drive largely by most states' EV regulatory policy (e.g. adopting California's Advanced Clean Cars regulation)

11%

Midwest

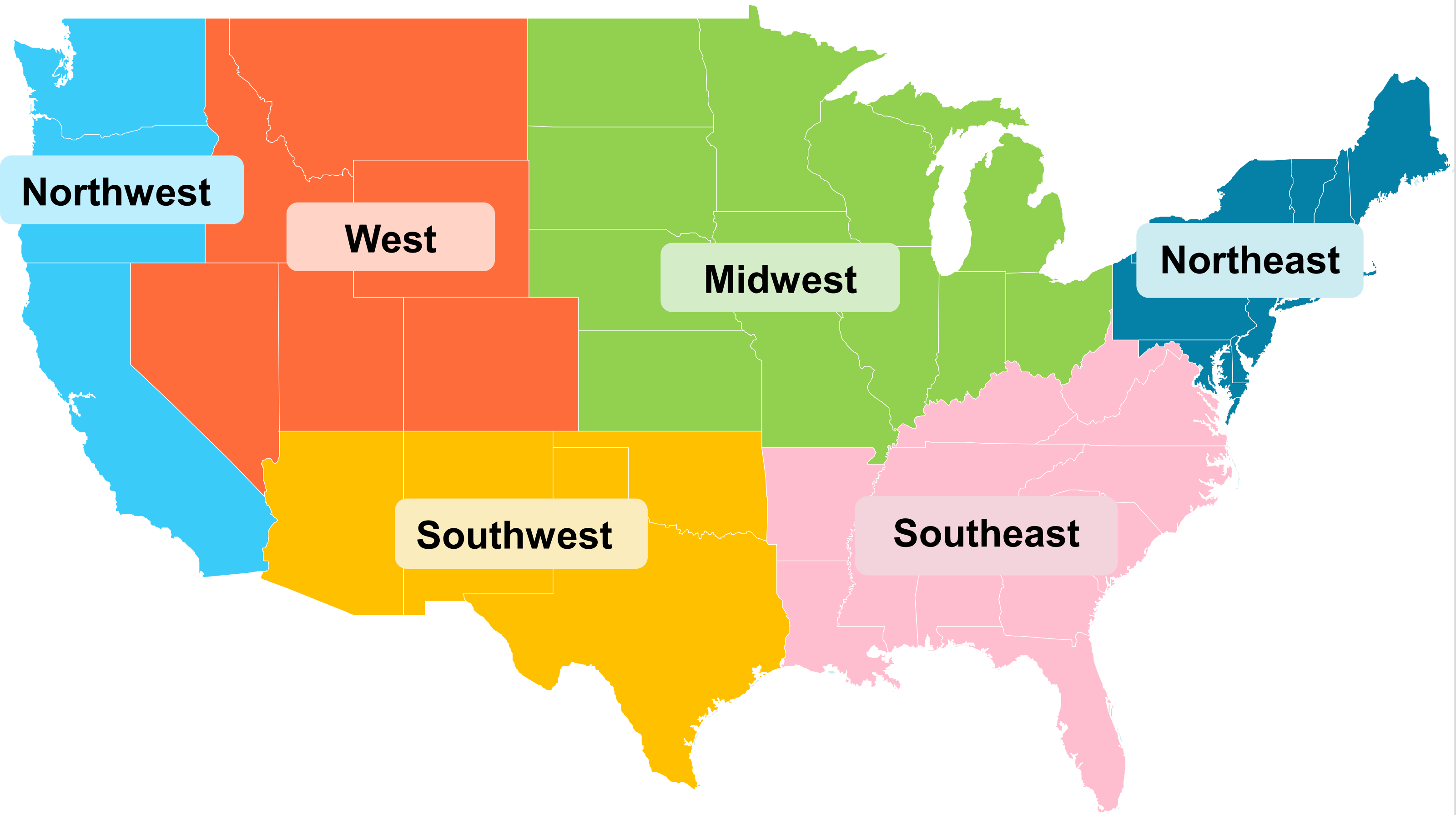
EV adoption relatively evenly dispersed (IL, MI, and OH are the main drivers), with high single-family home access, some state EV policies driving adoption.

6%

West

The lowest region for EV adoption, cause by a lack of state EV regulations, rural geographies, unfavorable climate, and a lack of charging infrastructure.

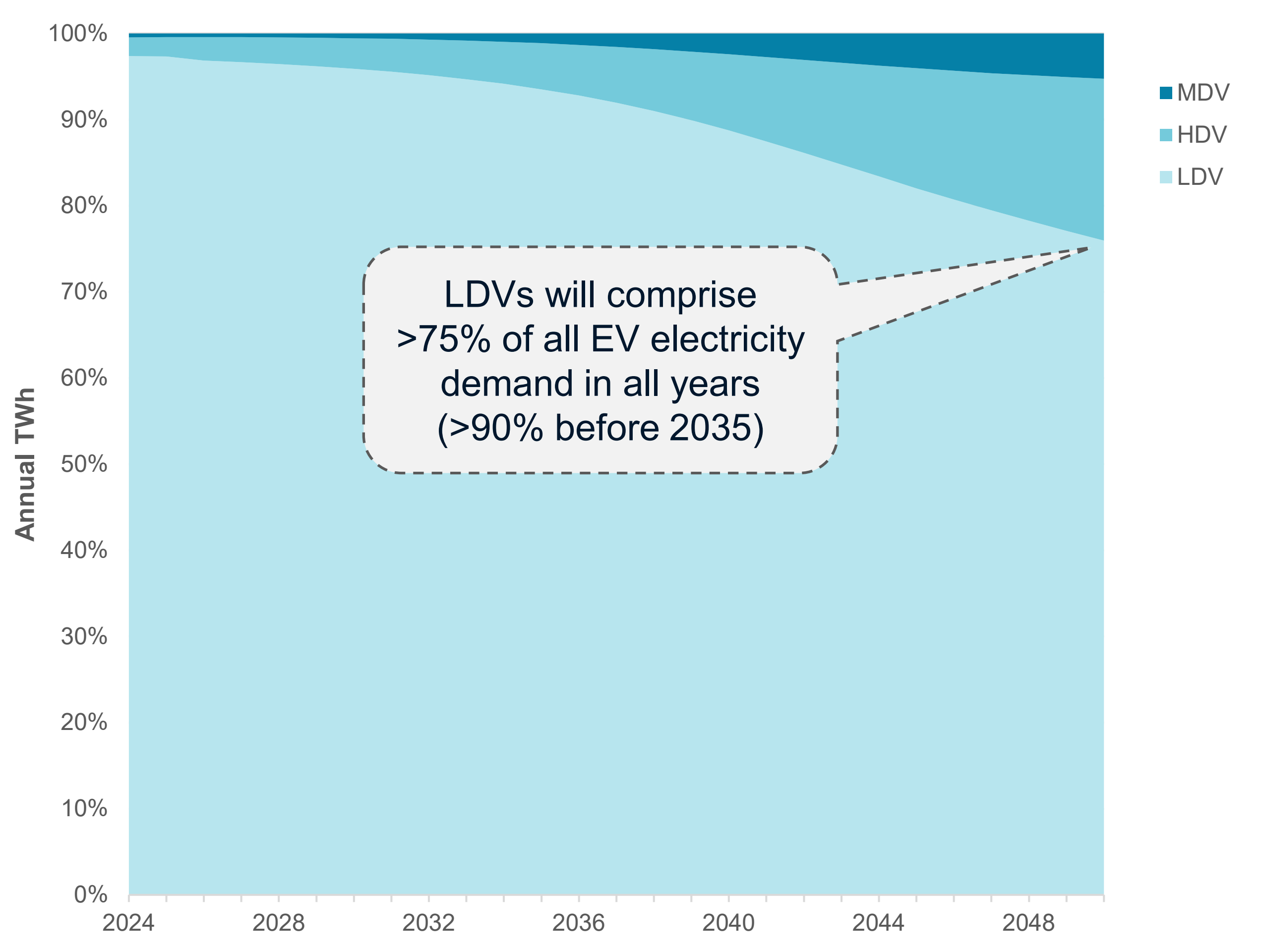
Projected Distribution Of EV Load In The US to 2035



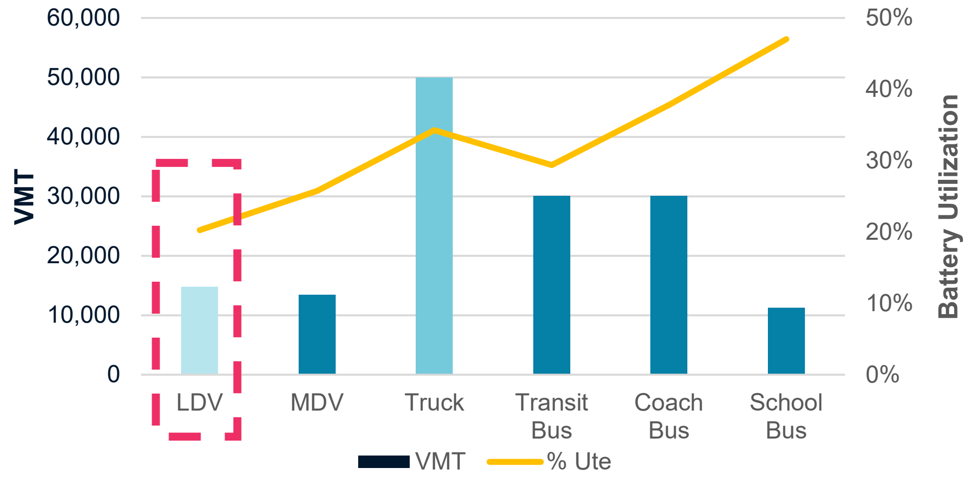
Source: PA Consulting 2024

LDVs will consistently comprise a minimum of 75% of all vehicle electricity consumption to 2050, and their lower battery utilization presents the best opportunity to deploy demand-based grid flexibility solutions relative to MDVs, trucks, and buses

EV Electricity Demand Breakout by Vehicle Class



VMT and Battery Utilization by Vehicle Class

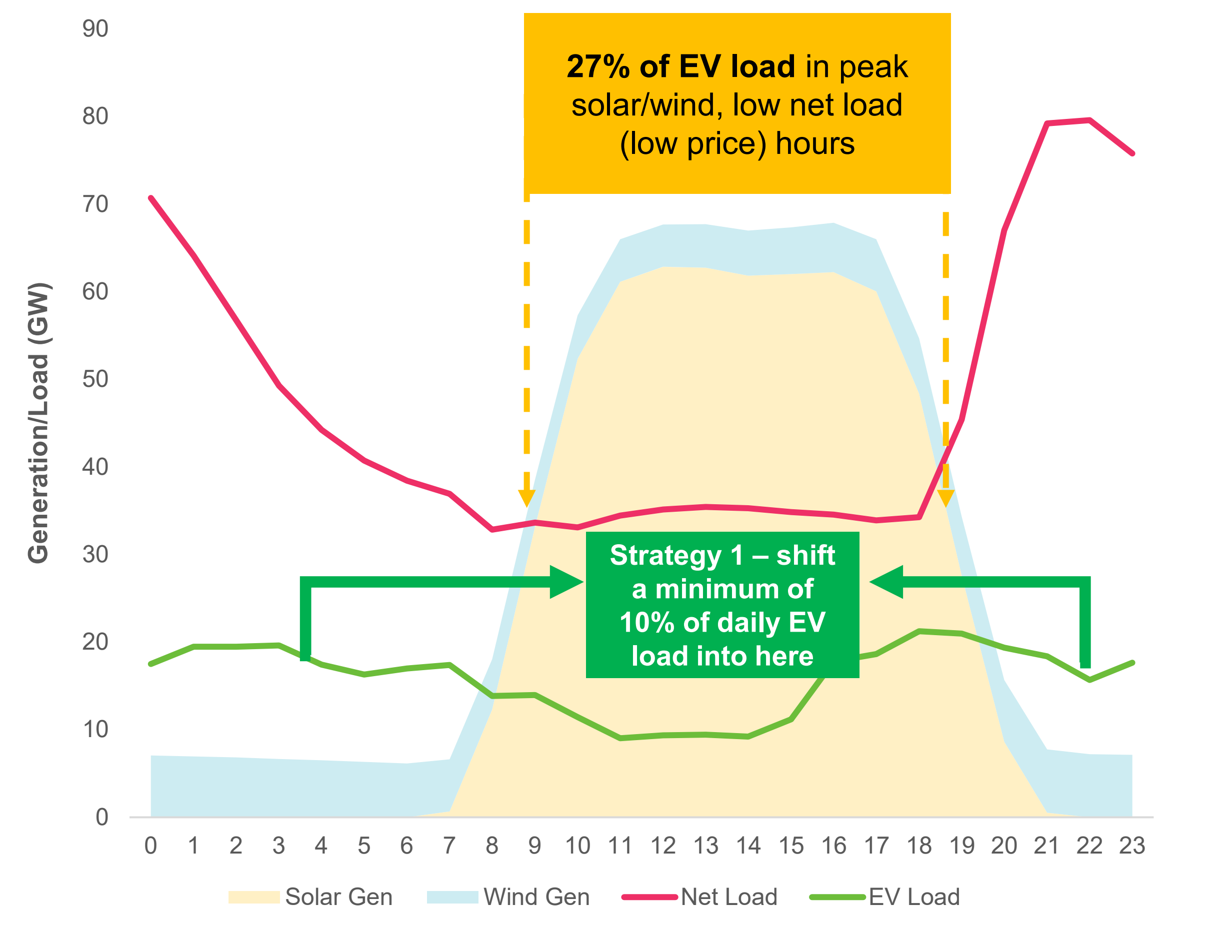


- *Battery utilization = eVMT * EV efficiency (kWh per mi) / (average vehicle battery size * 365). It is a metric of how much energy the vehicle uses, relative to how much it would use if it depleted its entire battery, every day of the year.*
- *LDVs have low annual VMT and relatively high efficiency, resulting in low battery utilization. This indicates high potential for grid services and availability for demand flexibility, relative to trucks, which have high battery utilization.*
- *Fleets comprise ~18% of all LDV sales[1]; fleet load is easier to aggregate (fewer owners), but has low flexibility due to fixed, essential trip demands (e.g. delivery vans that must drive during certain hours)*

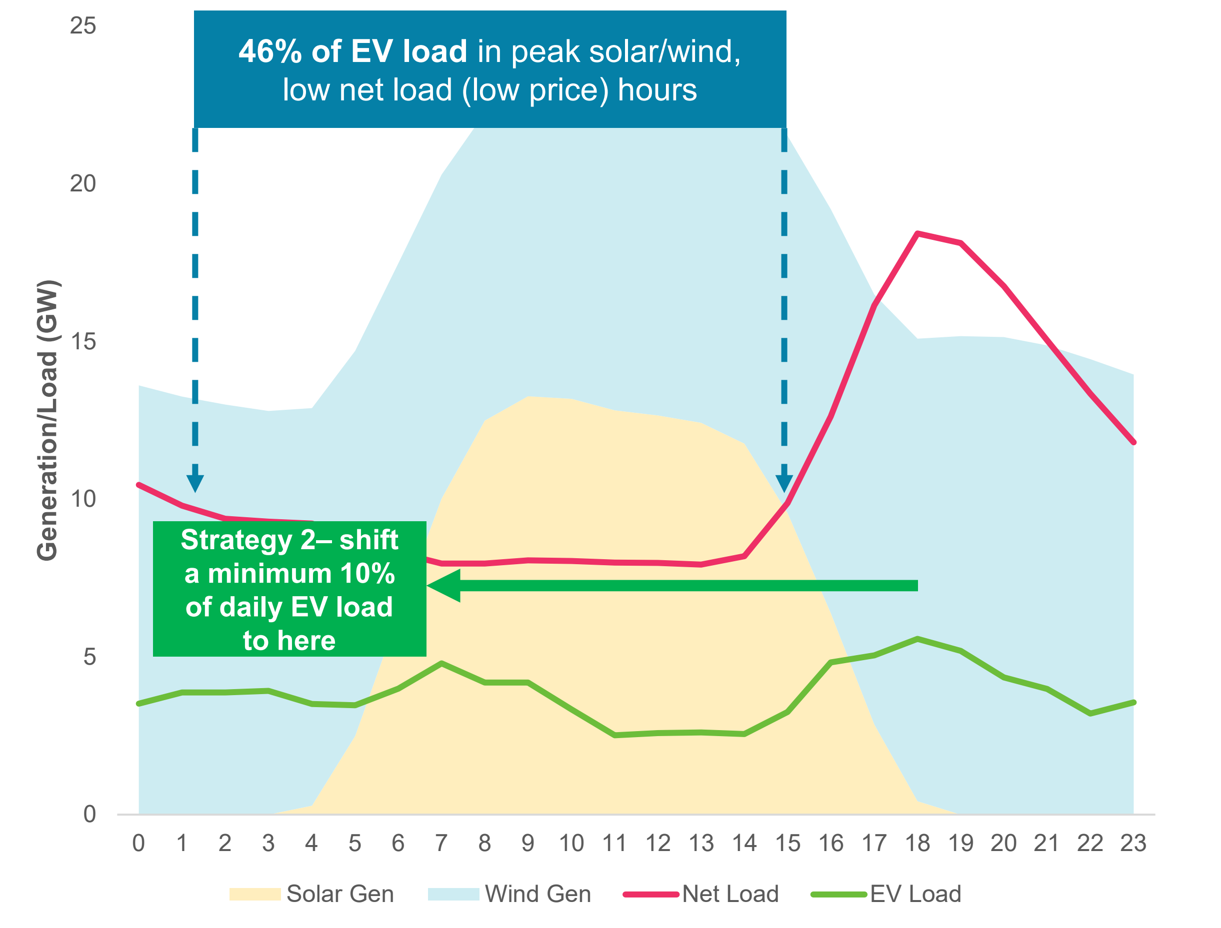
[1]*Source: Cox Automotive, PA Analysis*

Comparing CA and NY under unmanaged charging scenarios, a much lower share of EV load will occur during cheap, clean hours in CA than NY (which will have much higher wind) – but in both cases huge opportunity to shift to periods of excess gen.

Shifting EV Load To Periods Of Excess Renewable Generation
Typical Day 2050 - High Solar Penetration State (California)



Shifting EV Load To Periods Of Excess Renewable Generation
Typical Day 2050 - High Wind Penetration State (New York)

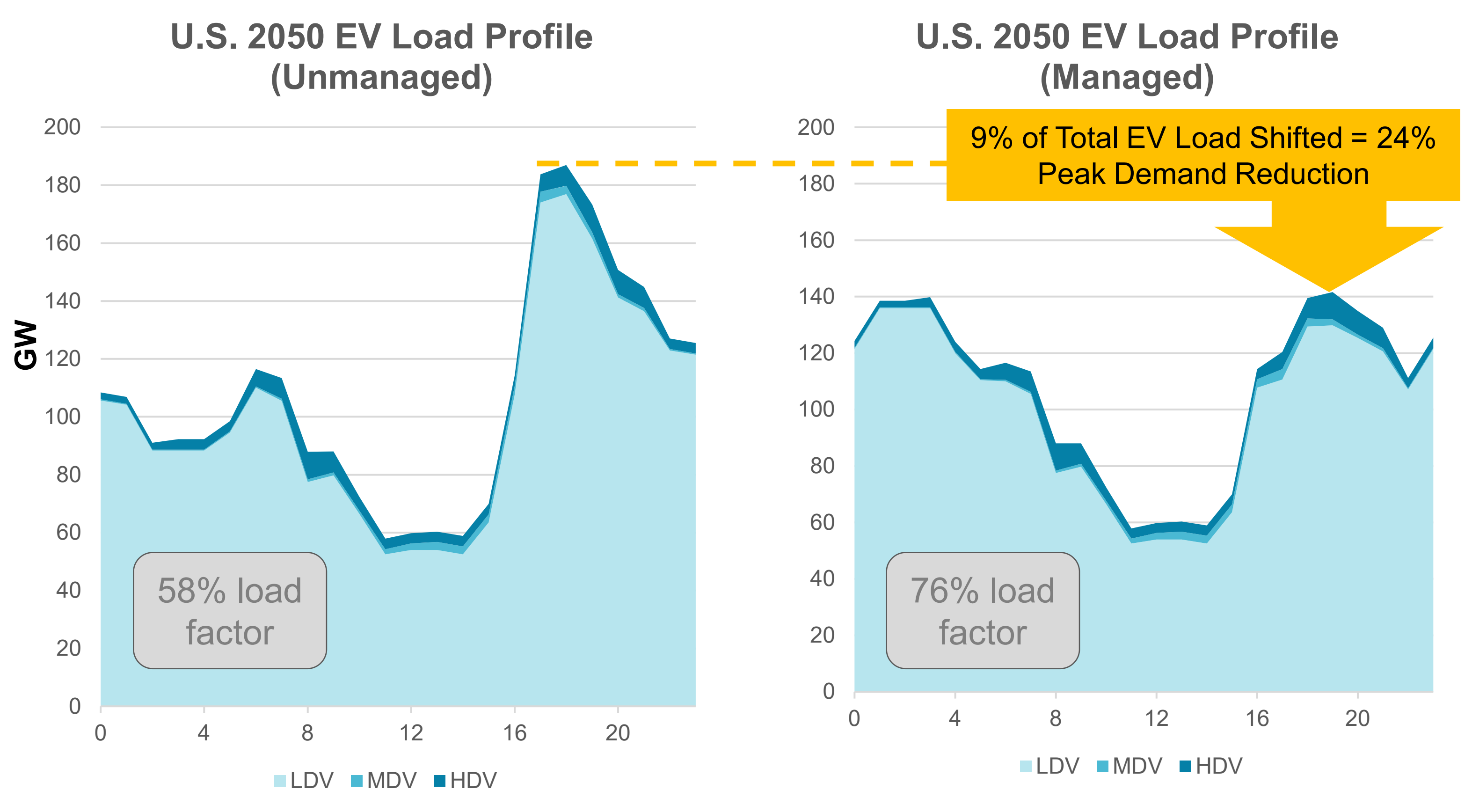


Source: PA Internal Modeling, NREL Cambium Model

By shifting less than 10% of daily EV charging demand in 2050 to times of excess renewable generation, peak EV demand could be reduced by nearly 25% and improve the overall efficiency of the grid to meet EV demand by 18%

- The equivalent of 3M EV's out of 200M shifting their charging patterns each day (1.5%)
- Unmanaged home EV charging in 2050 could result in ~180GW of peak EV load, occurring at 7pm, in addition to a steep ramp from mid-day
- Managed home EV charging in 2050 could result in a 24% reduction in peak EV load, to ~140GW, which occurs more evenly in both the early evening (6-7 PM), as well as the overnight hours (1-2 AM), with a mid-day lull still occurring
- The managed charging scenario results in a load factor (a measure of grid efficiency, or the ratio of average to peak load) of 76%, relative to 58% in the unmanaged scenario

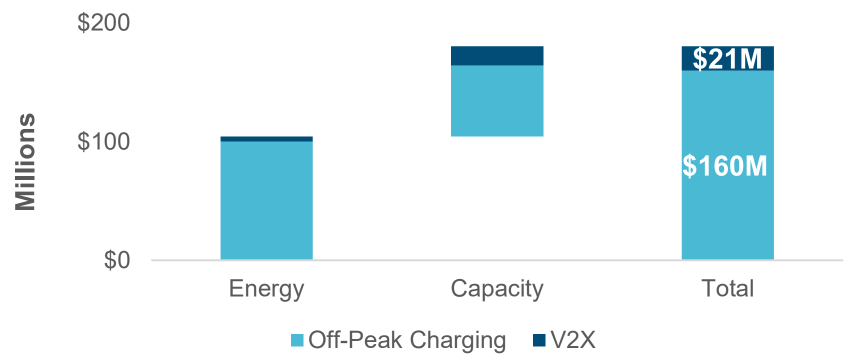
Daily Load Shifting of ~200M U.S. EV Fleet by 2050



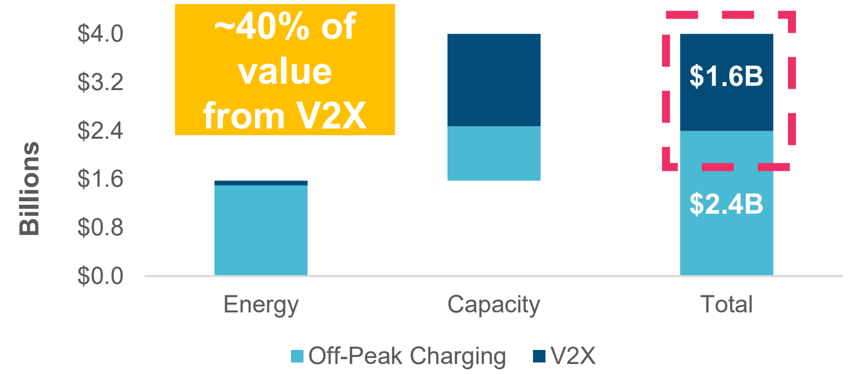
Source: PA Consulting 2024

Quantifying the opportunity – shifting a conservative amount of EV load to lower-cost hours, as well as leveraging EV batteries for arbitrage/capacity value could result in $181M in annual value to the grid and to customers by 2030 rising to ~$4B by 2050

2030 Flexibility Value By Technology & Energy Area



2050 Flexibility Value By Technology & Energy Area



Sources of Value	Energy	Capacity
Off-Peak Charging	Energy arbitrage value of shifting a slice of total electricity demand to off-peak, lower-cost hours, for all days [3% in 2030→5% in 2050, saving $30/MWh]	Capacity value of reducing peak EV demand through same off-peak shift, for all peak days each month [3% in 2030→5% in 2050, saving $5/kW-mo.]
Vehicle to Grid or Home / Workplace (V2X)	Energy arbitrage value of injecting tangible amount of EV energy back into home/grid, for a small number of days per year [12% of daily energy, 9 days/year by 2030→18 days/year by 2050, saving $14/MWh]	Capacity value of injecting tangible amount of EV energy back into home/grid, for a small number of days per year [1% of all LDV EVs shaving peak demand at 2kW/EV, for 3 days/month, 3 months/year in 2030→3% of all LDV EVs shaving peak demand at 4kW/EV, for 3 days/month, 6 months/year in 2050, saving $10/kW-mo.]

Source: PA Consulting 2024

Growth in storage will vary significantly from region to region driven by mostly by the pace of renewable generation growth, thermal capacity retirements, and intra-day energy price variation (energy arbitrage value)

22%
Southeast
Storage deployment equal to other regions largely due to widespread geography, within the region, growth is moderate, driven by elevated capacity prices.

22%
Northwest
High current storage deployment, significant renewable energy penetration drive growth, mostly in Californai

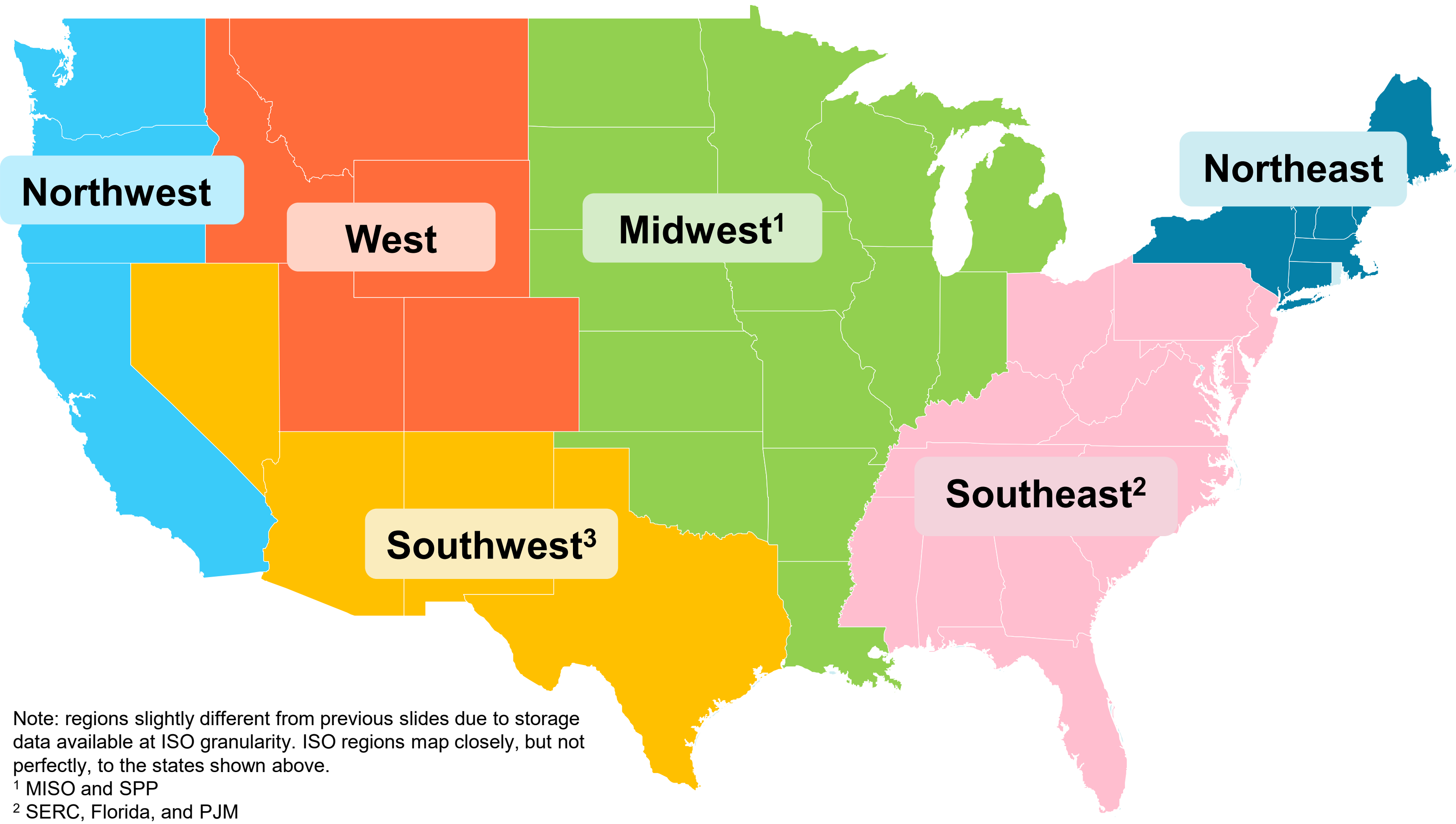
22%
Southwest
Significant renewable growth, paired with favorable storage economics in Texas (high arbitrage value) drive significant growth

7%
Northeast
Relatively low storage deployment due to smaller geography, energy demand, existing clean resources (e.g. hydro).

24%
Midwest
MISO (eastern part of the region) drives nearly all storage growth, as utilities look to replace firm capacity from coal plant retirements and pair with renewables.

3%
West
Lowest storage deployment region, due to low renewable energy penetration, utility targets (with Colorado an exception).

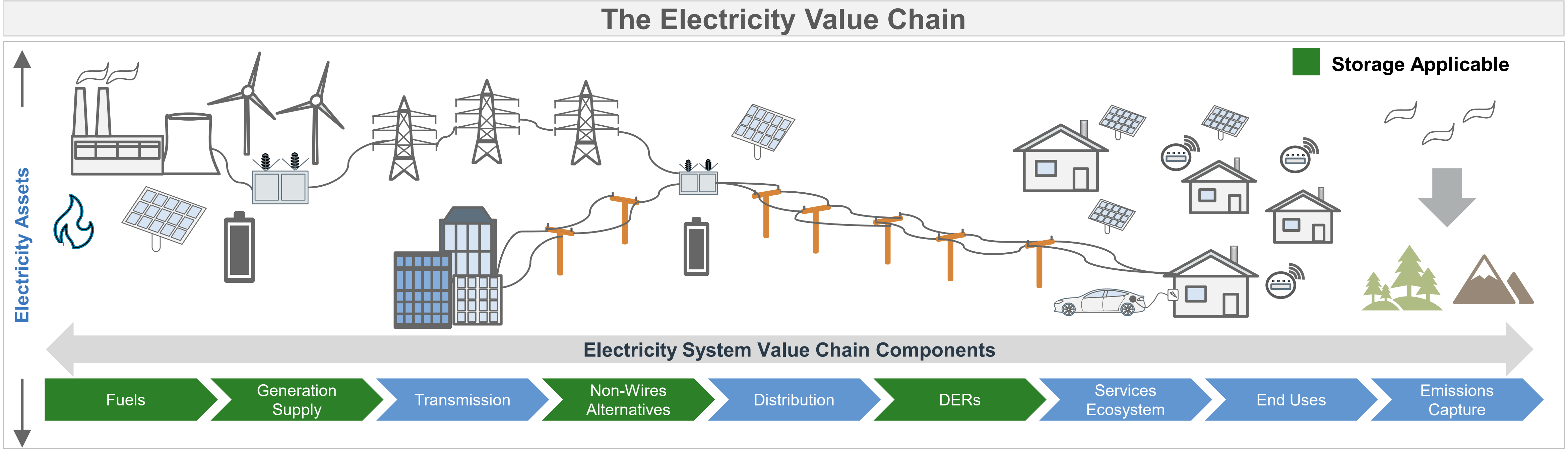
Projected Distribution Of Storage In The US to 2035



Note: regions slightly different from previous slides due to storage data available at ISO granularity. ISO regions map closely, but not perfectly, to the states shown above.
[1] MISO and SPP
[2] SERC, Florida, and PJM
[3] Desert Southwest Region & ERCOT

Source: PA Consulting 2024

There are several critical places in the electricity system that battery storage can deliver economic and operational value



Value Chain Component	Battery Energy Storage System Value Mapping
Fuels	Blurred line with Generation Supply; most applicable to hydrogen and, potentially compressed air energy storage
Generation Supply	Charging from grid (or on-site renewables) and discharging to grid when power is needed – supply balancing
Non-Wires Alternatives	Alternative to T&D CapEx, primarily for reliability or capital infrastructure investment offset
DERs	Similar to Generation Supply, but at the C&I or residential level + resilience

Source: PA Consulting 2024

There are four primary roles for battery energy storage system solutions on the US electricity grid: this section's focus is on wholesale, which comprises the vast majority of storage deployments

01 Wholesale

- **Who can participate:** Many players, including developers, IPPs, LSEs under a myriad number of participation models.
- **What is the monetization opportunity:** Covering reliability events via existing capacity products, new capacity products, and new ancillary products; may be short-term arrangements.
- **Where is the need:** Formalized ISO/RTOs.
- **Why is there a need:** (i) Balancing short-term grid intermittency via energy arbitrage and ancillary services; (ii) supporting firm capacity needs during peak periods; and (iii) providing backup during reliability events.

02 Grid (Transmission & Distribution)

- **Who can participate:** Primarily incumbent LSEs, which can create significant barriers to entry; evolution in market tariffs(e.g., MISO and SPP) and FERC policy may further open the door to private participation, but opportunities likely to remain limited/sparse.
- **What is the monetization opportunity:** Deferring T&D CapEx for reliability via long-term contract or BOT arrangements.
- **Where is the need:** Owners of T&D systems (primarily vertically integrated LSEs).
- **Why is there a need:** Deferral of T&D costs via siting of storage acts as an alternative to service multiple grid needs (including reliability over multiple timeframes); however, very site specific.

03 Regulated (Wholesale/Grid)

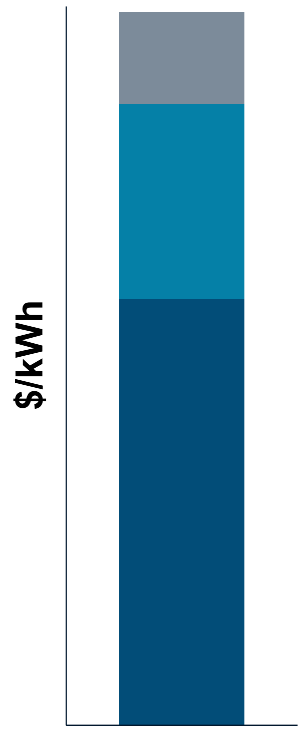
- **Who can participate:** Like current RFP processes in vertically integrated regions, open to all market players, however, there may be some bias toward LSE self-build. However, benefit to competitors is the ability to "stack" multiple value streams.
- **What is the monetization opportunity:** Creating multiple value streams from value stacking via long-term PPAs or BOT arrangements.
- **Where is the need:** Formalized ISO/RTOs; LSEs in vertically integrated regions, including those participating in ISO/RTOs (e.g., MISO and SPP).
- **Why is there a need:** A combination of Wholesale and Grid needs, including acting as firm capacity for retirements.

04 Customer (Behind The Meter - BTM)

- **Who can participate:** BTM-focused entities with strong customer acquisition skills/relationships, combined with market-leading technological and software solutions.
- **What is the monetization opportunity:** Likely limited outside of the context of microgrids that prioritize multi-day reliability (e.g., island contexts).
- **Where is the need:** Regionally agnostic, but primarily C&I customers (with some residential potential).
- **Why is there a need:** Helps with avoidance of C&I demand charges; as DER aggregation matures, allows ability to participate in wholesale arbitrage and reliability context.

Source: PA Consulting 2024

Multi-Hour lithium-ion battery storage value breakdown - Fundamentally, BESS projects provide three main value streams to the electric grid



Ancillary Services: Keeping the Grid Reliable

- Ancillary products include regulation and operating reserves (including 10-minute spinning, 10-minute non spinning, and 30-minute operating); as well as cost-based ancillary services (e.g., reactive power and black start).
- Batteries, with their instantaneous ramp abilities and flexibility, are well-suited to provide most ancillary services.
- ISO markets are expanding ancillary volume procurements to manage greater intermittency from renewable resources and thermal retirements.

Capacity: Displacing Typical Dispatchable Resources to Meet Peak Demand

- ISO markets typically have a formal market for capacity sales. In PJM this is the Base Residual Auction (BRA), and in MISO the Planning Reserve Auction (PRA). However, in MISO, most capacity transacts bilaterally before the PRA is held.
- Non-ISO markets (DSW, PNW, and SERC), have bilateral capacity markets, which require contracts to liquidate (typically with an electric utility.
- The value of capacity provided by battery storage (as measured by Effective Load Carrying Capability (ELCC)) is forecasted to decline as more storage resources enter the market.

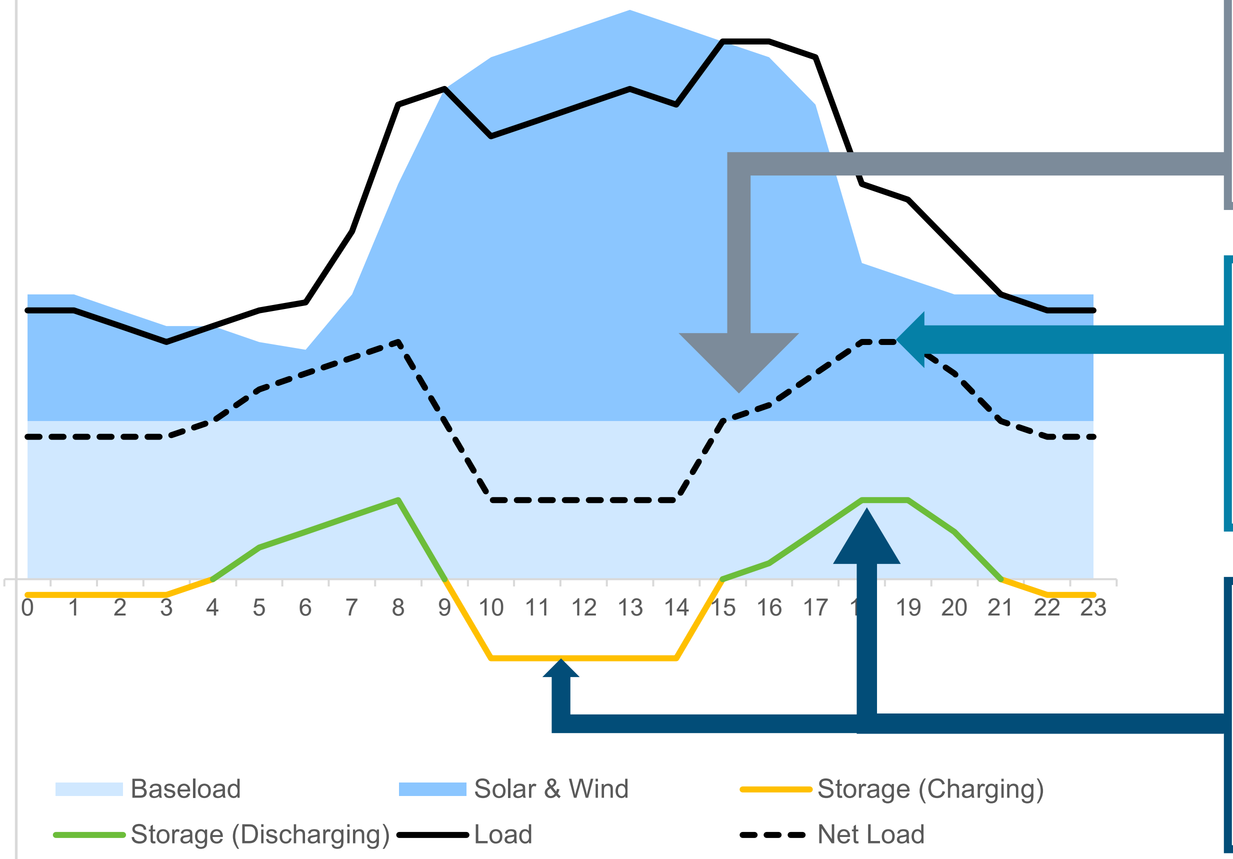
Energy Arbitrage: Charging with Cheap, Clean Electrons, and Discharging to Displace Dirty, Expensive Electrons

- Storage resources participate in PJM and MISO's day-ahead and real-time energy markets. In the bilateral markets, there is only a single energy market that is coordinated by the regional electric utility (e.g. Georgia Power).
- Near to mid-term arbitrage opportunities are expected to increase as the U.S power markets' existing thermal capacity, traditionally base-load generators, retire and are replaced by intermittent wind and solar generators.
- Over time, increasing storage penetration will partially temper load growth and market volatility, though the pace of solar and wind additions is expected to far outpace storage additions and still drive energy arbitrage value.

Source: PA Consulting 2024

Energy storage value stream visualization - As more intermittent wind and solar generation is relied on to serve electricity demand, the need for battery storage to support electric grid reliability will increase and provide three distinct value streams

Illustrative Battery Storage Dispatch Profile



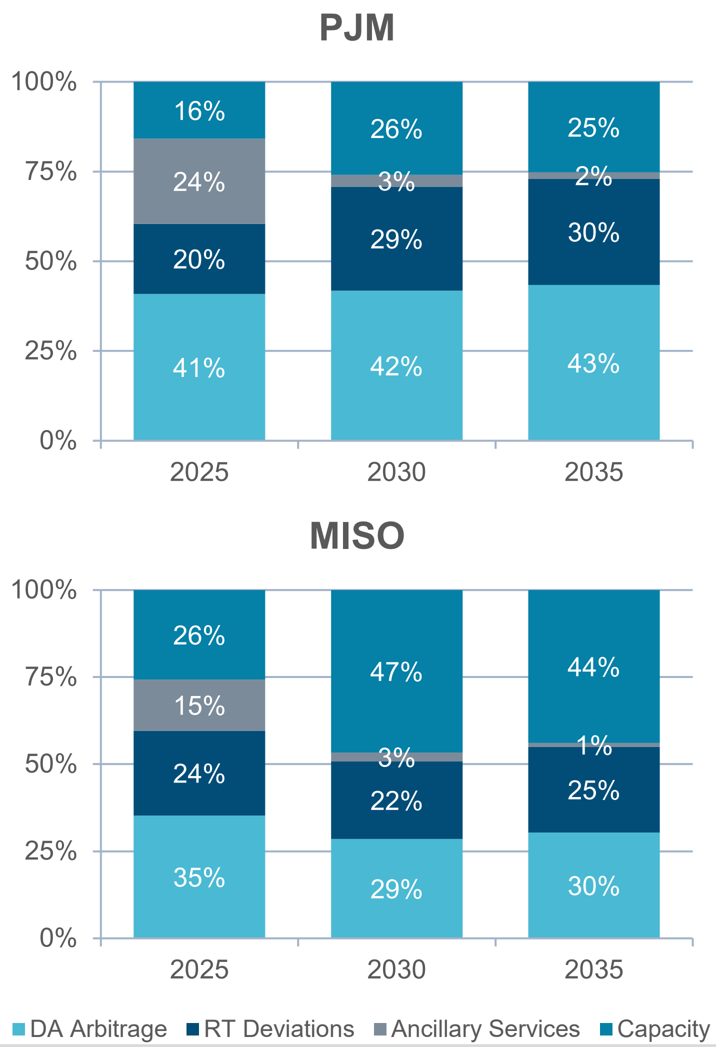
Ancillary Services: batteries provide fast-ramping resources to meet increasing demand during the early evening/turn on at a moment’s notice when other plants trip offline, displace fossil peaker plants

Capacity: provide firm capacity for the four peak evening hours, getting paid from the ISO for providing reliable capacity

Energy Arbitrage: charging during mid-day, cheap solar hours, and discharging during expensive, natural gas peaker plant hours

Source: PA Consulting 2024

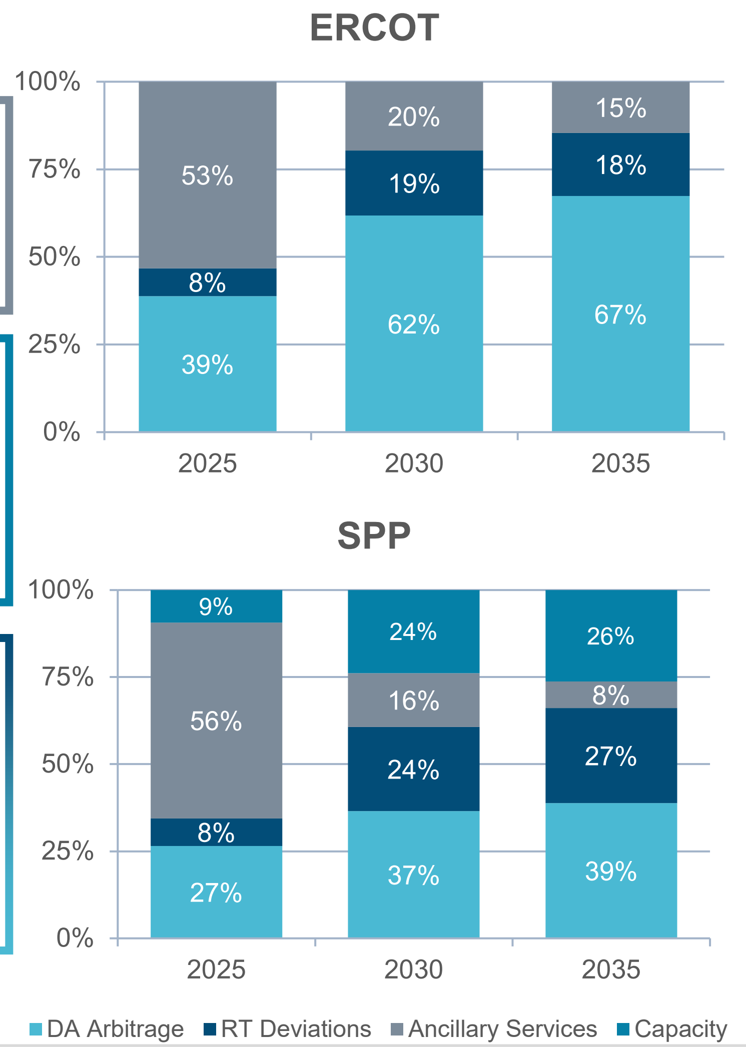
The value stack for energy storage will likely vary from region to region and will change over time as the energy transition matures; the greatest long-term value will come from energy arbitrage, relative to capacity and ancillary services



Ancillary Services: highest in ERCOT and SPP, but diminishes in all regions to near-zero over time, as market becomes saturated with storage

Capacity: significant revenue stream in all regions over time (except ERCOT, which has no capacity market), especially as firm capacity retires (coal)/fails to come online (gas)

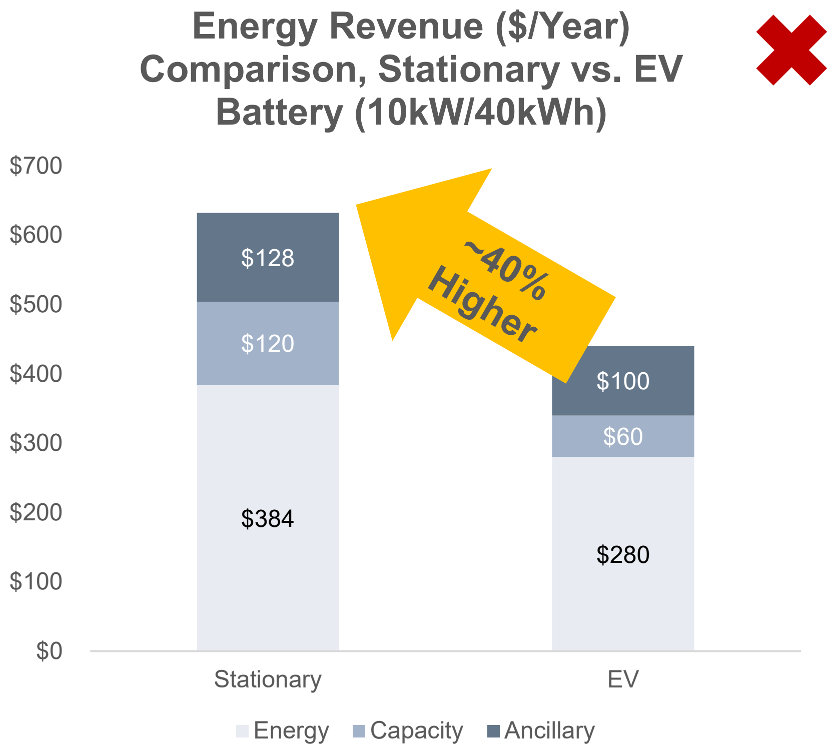
Energy Arbitrage: day-ahead (DA) arbitrage generates more revenue than real-time (RT), as most batteries take advantage of predictable next-day price signals, with some additional arbitrage done in real time should price spreads become larger



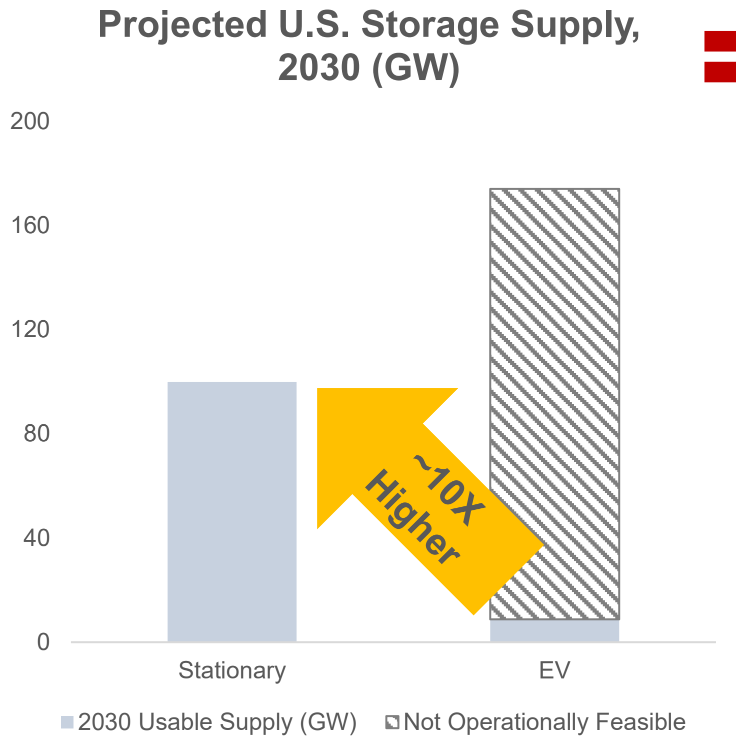
Note: Values reflect 4-hour storage and are from recent PA analysis in each market.

Energy Storage

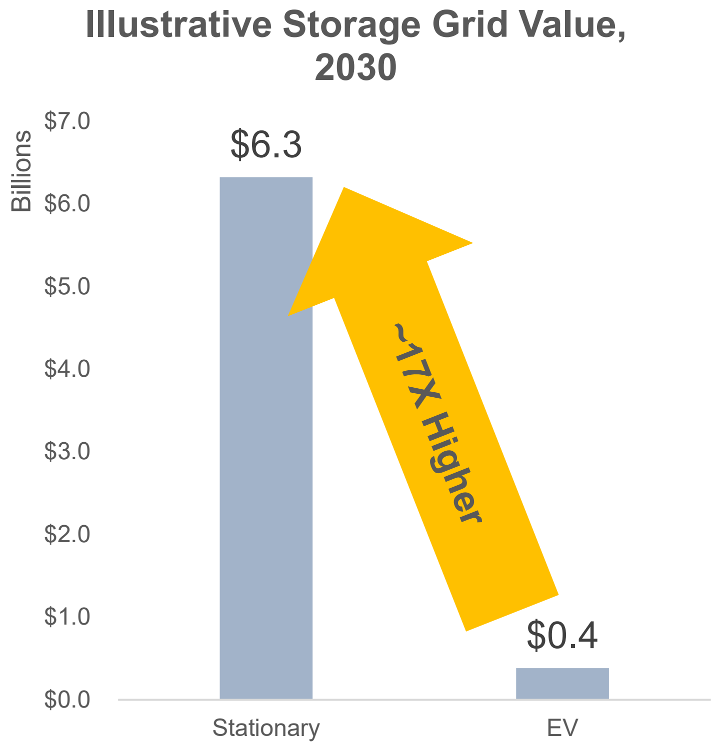
Grid value of utility-scale stationary storage vs. EV battery storage - Stationary batteries would make ~40% more revenue (per kW), comprise 10X the deployments, and thus generate 17X the overall grid value of EV batteries



Stationary storage has higher energy arbitrage price spreads, operates for more days/year, rated for higher firm capacity per MW than EV storage.
[Source: 2023 PJM Market Data]



While the battery capacity of all 2030 EVs (outputting at 7kW) is nearly double that of utility-scale stationary storage, operational limitations result in the latter exceeding the former's capacity by ~10X.
[Source: PA Projections]



Multiplying the energy revenue per GW by the number of GW of storage for each use case yields a total value ~17X higher for stationary storage than that of EVs.

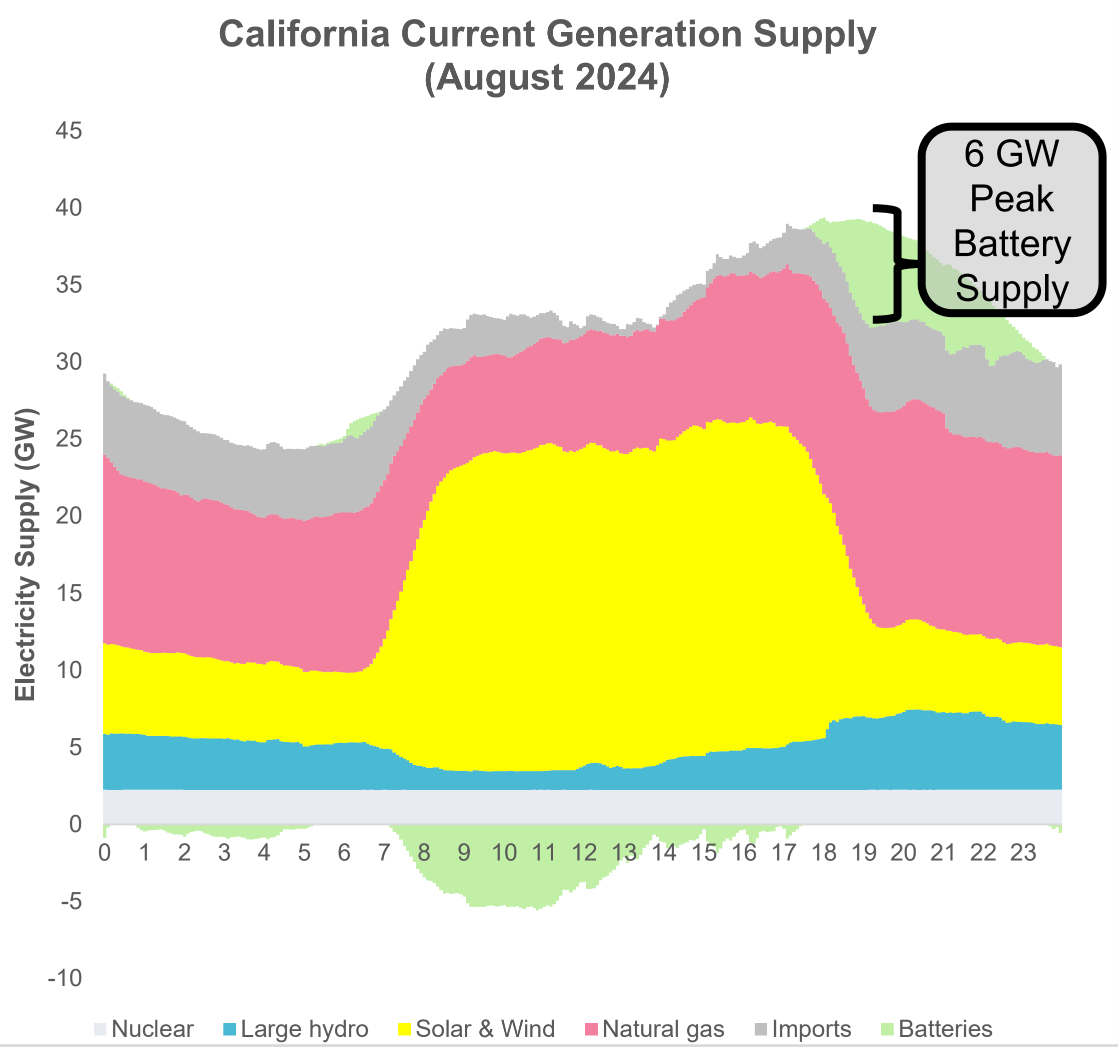
Source: PA Consulting 2024

Today's ~10GW of grid-scale battery storage in CAISO generates ~$800M in annual wholesale value, 1.3 million tons in CO2 annual avoidance; 30GW storage by 2040 increases value to $1.8B, 4 million tons

- Today's 10GW of grid-scale battery capacity avoids 6 GW of peak demand, from actual CAISO market data from August 21, 2024 (not all capacity is discharged/called upon each day)
- This battery capacity generates ~$800M in market value, from energy arbitrage, capacity, and ancillary services, and avoids 1.3 million metric tons (MMT) of GHGs annually
- Assuming similar market values by 2040, but 30GW projected storage capacity yields $1.8B and 4 MMT GHG/yr in benefits

CAISO Value Area	Today	2040
Installed Storage Capacity	10 GW (~40 GWh)	30 GW (~120 GWh)
Peak Demand Avoidance	6 GW	19 GW
ISO Market Value (Energy, Capacity, Arbitrage)[1]	$800M	$1.8B
Annual GHG Avoidance	1.3 MMT/yr	4 MMT/yr

[1] Assumes $30/MWh avg. daily arbitrage spread, $3/kW-mo. capacity value (50% capacity accreditation by 2040), $4/MWh ancillary services value through 2040, with storage cycling 300 days/year,
[2] Assumes a 0.1 ton CO2/MWh emissions rate differential between battery charging times at mid-day (~0.2 tCO2/MWh) and discharging times in early evening (~0.3 tCO2/MWh), and full cycling for 300 days/year



Source: PA Consulting 2024

BESS regulations and rule makings - with the rapid growth in BESS penetration, market operators are playing catch-up as they seek to design rules governing BESS participation and contribution to system reliability

While, broadly speaking, market operators are largely supportive of BESS participation, concerns around over-compensation and performance – justified given the limited track-record for BESS – and subsequent rule-making, could hinder the rate of BESS adoption.

NYISO Zone J Reference Unit

- In a marked departure from the past, NYISO has proposed moving to a 2h BESS as the reference unit as part of its quadrennial demand curve reset.
- With this move, the ISO will be the first to formally adopt a BESS reference unit, which also acknowledges the challenges associated with building new thermal generation in regions with strong decarbonization targets.
- Issues that the operator is still working through include the assumed derate factors, EAS offsets, and potential evolution in ELCC/reliability contribution over the near- to mid-term.

ERCOT Nodal Protocol Revision Request 1186

- ERCOT proposed NPRR 1186 to give the operator better visibility into BESS SOC and ability to meet A/S commitments.
- The proposal would have imposed additional telemetering requirements and increased the risks/penalties associated with A/S deployment and under performance.
- In early 2024, the PUCT unanimously rejected the proposal over concerns that the proposal would slow BESS development, at a time of rapid demand growth in the region, and the potentially discriminatory nature of the rule that singled out BESS (over thermal resources).

CAISO Bid Cost Recovery Payments

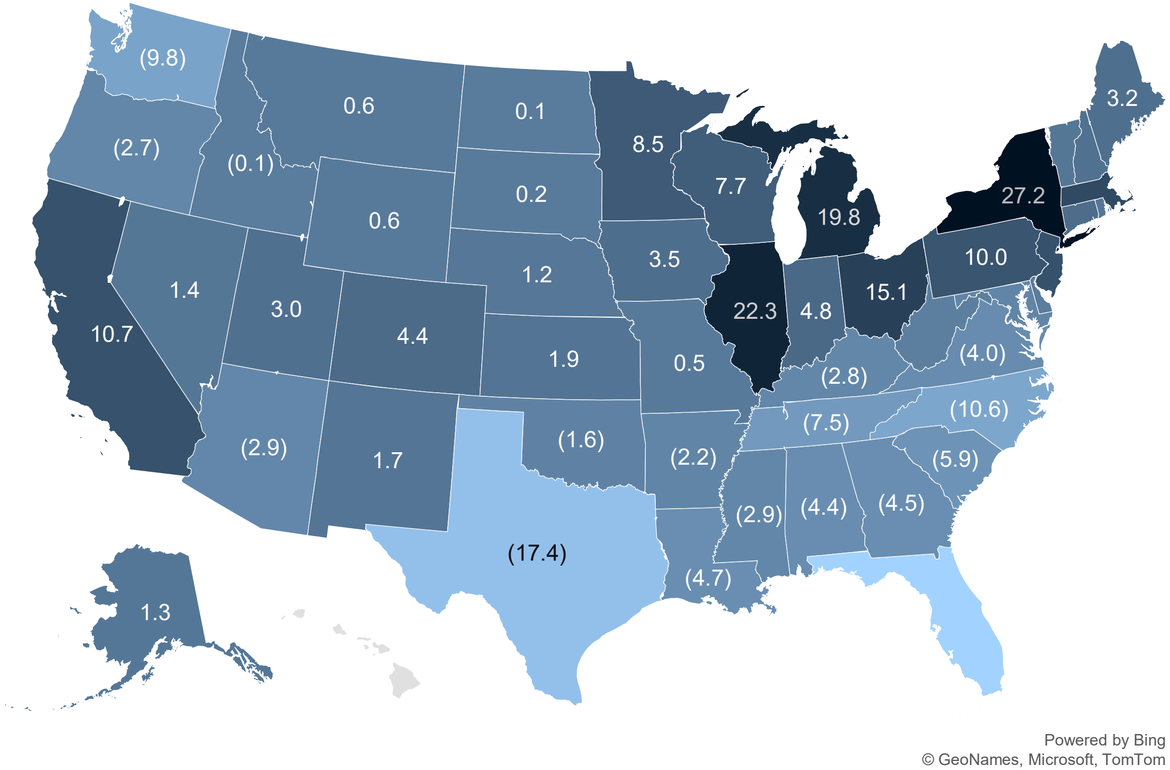
- CAISO proposed revising/lowering BCR payments awarded to BESS as the current program structure doesn't sufficiently consider SOC limitations and could result in unusually high payments to BESS resources.
- The operator's proposed solution sought to redefine dispatch unavailable due to SOC constraints as 'non-optimal energy' and ineligible for BCR.
- However, the operator is now reconsidering its proposal over concerns regarding challenges in implementing and the efficacy of the proposal in lowering BCR payments.

Source: PA Consulting 2024

As with other areas of consumption, residential load growth will be different across the U.S. - with increased demand in colder climates and decreased demand in southern climates

Load growth in residential sector by 2050[1] (TWh)

Pace and scale of building electrification varies from state to state. Most states with stringent climate targets are the ones in regions where building electrification will add to the electric load (e.g., NY, IL, CA, MI, CO), while states that can benefit from building electrification in form of net load reduction (e.g., TX, FL) have no stringent schedule to speed up building electrification.



Cold climate regions (e.g., Midwest, Northeast) will experience the highest growth in electric demand from electrification of buildings. As a result, annual peak is forecasted to shift from summer to winter.

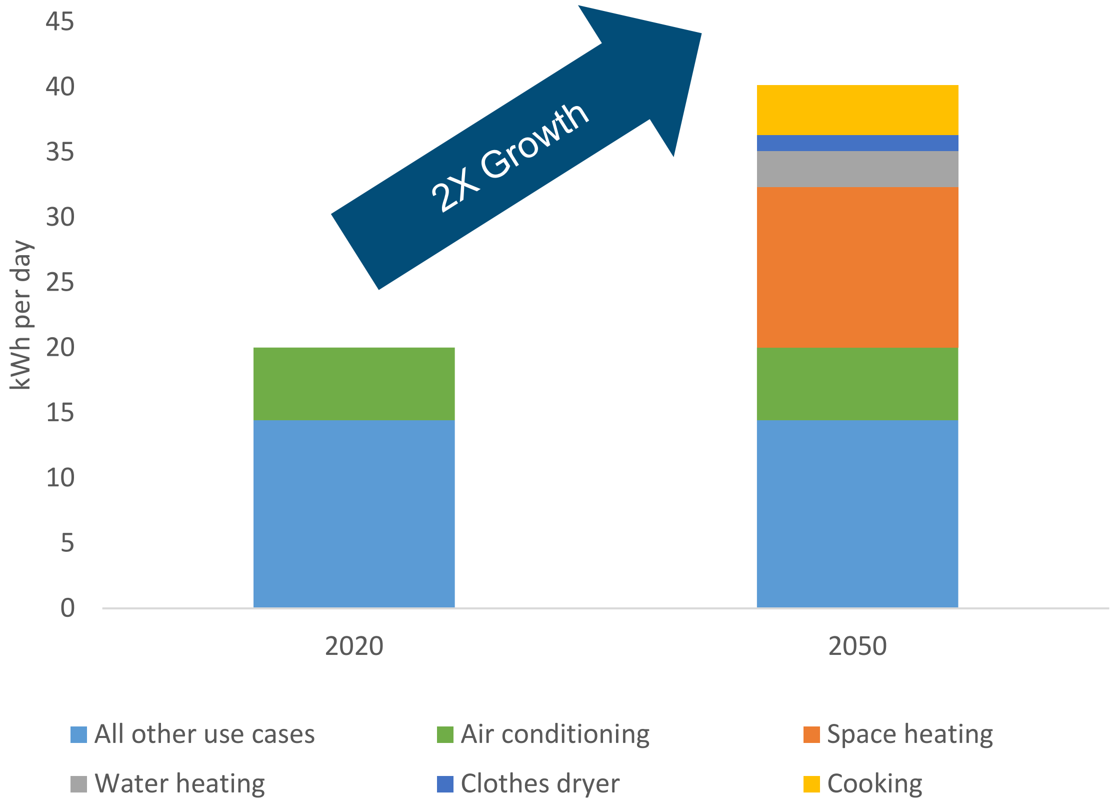
Warm climate regions (e.g., South) are already relying on electricity for space/water heating. Standardizing the use of more efficient technologies (e.g., heat pumps) can significantly reduce the electric load and peak demand in these regions.

[1]Source: NREL, Electrification Futures Study

Electrification of buildings could potentially double the average electricity use of a typical residential building in the U.S.

Electricity use in a typical home pre and post electrification of gas appliances[1]

A typical residential customer without electrified appliances in the U.S. consumes on average **20 kWh of electricity per day[2]**.



Upon electrification of gas appliances (e.g., space heating, water heating) the average daily energy use of such a customer would more than double to **40 kWh per day[2]**.

Load for common appliances such as dryers (2-5kW), AC (3-5kW), dehumidifier (~1kW), electric water heaters (~5kW), EV (8-10kW) are all flexible. The challenge will be bringing in participation from millions of devices and homes through technological and policy means.

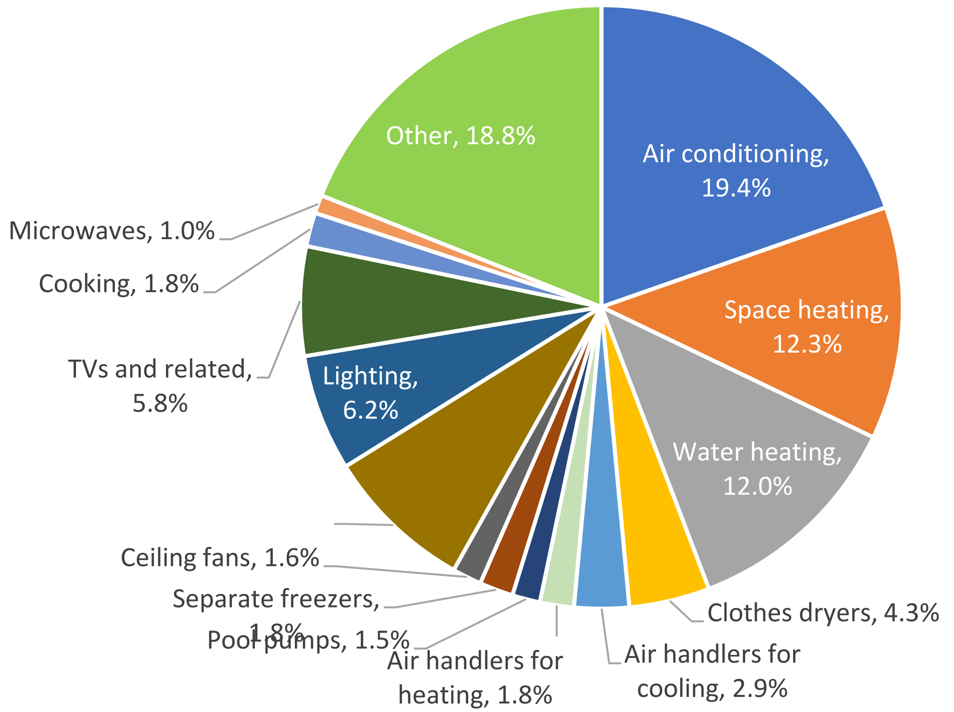
[1] Source: EIA, energy use in homes, 2020

[2] There will be variations in this average value based on climate, seasons, efficiency of appliances in use, personal behavior, etc. This figure assumes efficient heat pumps are used for space/water heating.

Source: PA Consulting 2024

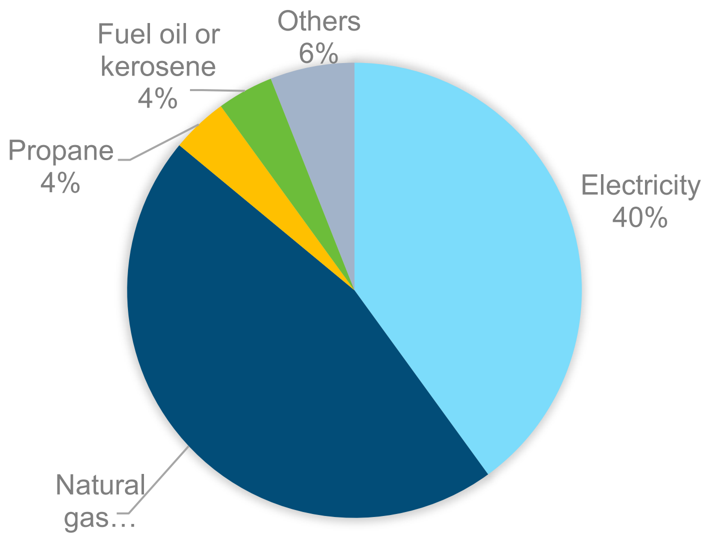
Within the home, space and water heating are prime potential areas of electrification

Share of end-use applications in the residential class[2]



- Heating & cooling makes up **43% of total residential energy use**[2].
- 89% of residential buildings in the US have air-conditioning, thus the potential for load growth from AC is small compared to space heating. Although there are opportunities to shift demand.
- Other use cases like refrigeration and lighting have already been electrified and have fewer opportunities for flexibility.

Primary space heating fuel in residential class[3]



- 56 million homes, **representing 46% of homes in the US use natural gas for space heating** and 40% use electricity.
- This represents a sizable flexible load opportunity.

Source: PA Consulting 2024

There is significant untapped load flexibility opportunities in the residential building sector, ranging from minutes to days

- There are significant flexibilities in operation of typical residential and commercial buildings, from minutes to hours (water heating, space heating, air conditioning) up to days (laundry and clothes dryer).
- Loads can be **shifted** around to avoid grid peak hours,
  - Water heaters can serve as "thermal energy storage" units, pre-heating water and reserving in tanks for hours to avoid operating during peak hours or grid emergencies without creating any discomfort for occupants.
  - Air conditioning and space heating can flex load for minutes to hours by pre-conditioning, cycling, etc. to avoid full load during peak hours
  - There are other smaller flexible load such as dishwashers, clothes washers, hot tub heaters, humidifiers, dehumidifiers, EV charging, and hot tub pumps.
- Certain flexibility applications can be implemented without sacrificing customer comfort (e.g. water heating) and some with full automation and minimal customer intervention (e.g. smart thermostats).
- More energy efficient technologies such as heat pumps and heat pump water heaters can significantly **reduce** the electric load. For example, heat pump water heaters are 3-4 times more efficient than typical water heaters.

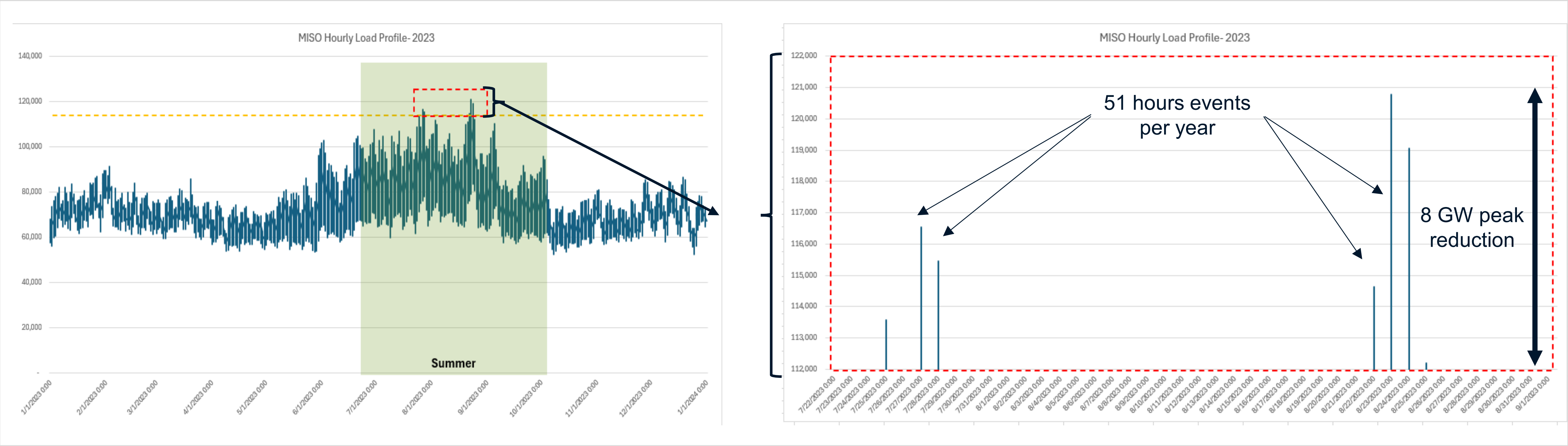
Decreasing Flexibility Potential

Load Flexibility by Residential End Use (Yes/No)				
End Use[2]	Relative Load	Overall Flexibility	Flexibility up to Minutes	Flexibility up to Hours
Air Conditioning	19.4%	Y	Y	Y
Space Heating	12.3%	Y	Y	Y
Water Heating	12.0%	Y	Y	Y
Clothes Dryers	4.3%	Y	Y	Y
Air Handlers for Cooling	2.9%	Y	Y	Y
Air Handlers for Heating	1.8%	Y	Y	Y
Pool Pumps	1.5%	Y	Y	Y
Separate Freezers	1.8%	Y	Y	N
Ceiling Fans	1.6%	Y	Y	N
Refrigerators	7.9%	Y	Y	N
Lighting	6.2%	Y	Y	N
TVs, cooking, microwaves	8.6%	N	N	N
Other	18.8%	N	N	N
% Flexible Load		**72%**	**72%**	**54%**

Source: PA Consulting 2024

Load shifting for space cooling can result in significant savings across the grid- MISO case study

- MISO is one of the largest ISOs across the US, covering all or portions of 15 Midwest and southern US states, stretching from Canada to Texas.
- MISO is currently a summer-peaking ISO, with ~121 GW peak demand in the summer and ~90GW in the winter[1].
- Pursuing grid flexibility opportunities by shifting a very conservative share of AC load for 51 hours over the course of 9 days in the summer can reduce MISO peak demand by at least 8 GW. A very conservative estimate suggests a minimum of ~$169M saving for customers per year.



Shifting a very conservative share of AC load for 51 hours over the course of 9 days in the summer can reduce MISO peak demand by at least 8 GW. A very conservative estimate suggests a minimum of ~$169M saving for customers per year

Source: PA Consulting & MISO 2023

Quantifying the opportunity – shifting a conservative amount of AC load by pre-cooling buildings could result in $169M in annual value to the grid and to customers in MISO, $573M across the US

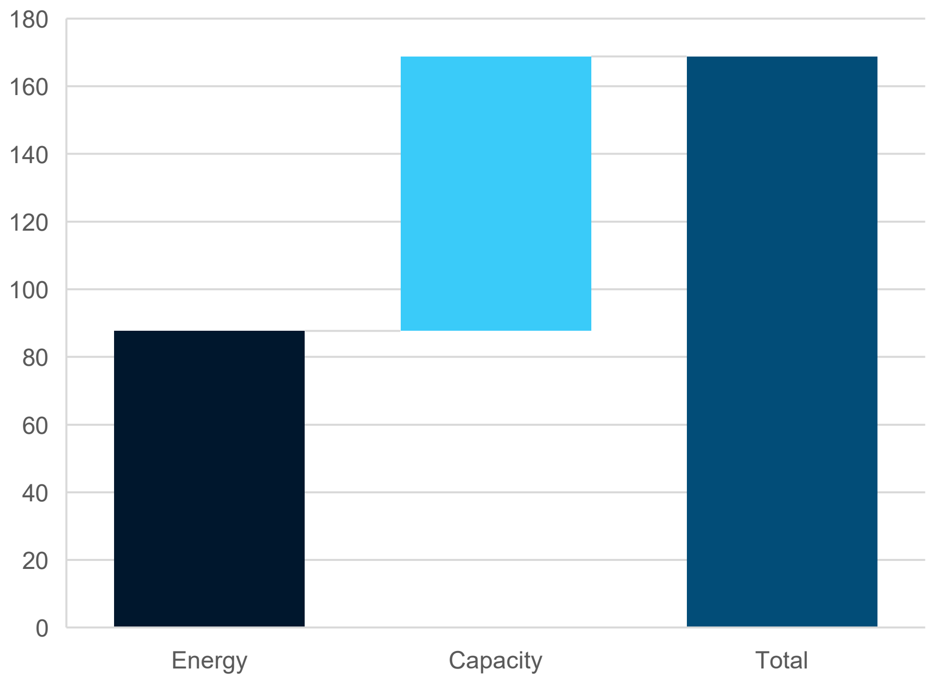
Key Assumptions

- There are nearly 18 million households residing in MISO across 15 states.
- 90% of homes are assumed to have AC units, with the average peak power draw of 5kW.
- 1 in every 10 customer is assumed to participate in a *Flexible AC Program*, to pre-cool their home and increase the temperature set during a 4-hour window*.
- The avoided cost of peak demand for generation is conservatively assumed to be $10/kW-mo.

Key findings

- Using MISO's 2023 load profile as a case study, such *Flexible AC Program* would only be needed for **51 hours over the course of 9 days** to reduce the peak demand by **over 8 GW**.
- Such a program would save rate payers at least **$169M per year** by avoiding new power generation capacity alone.
- Scaling up such a program across the US could result in up to $500 M per year savings.

2024 Grid Flexibility, Value of AC Flexibility ($million/year)

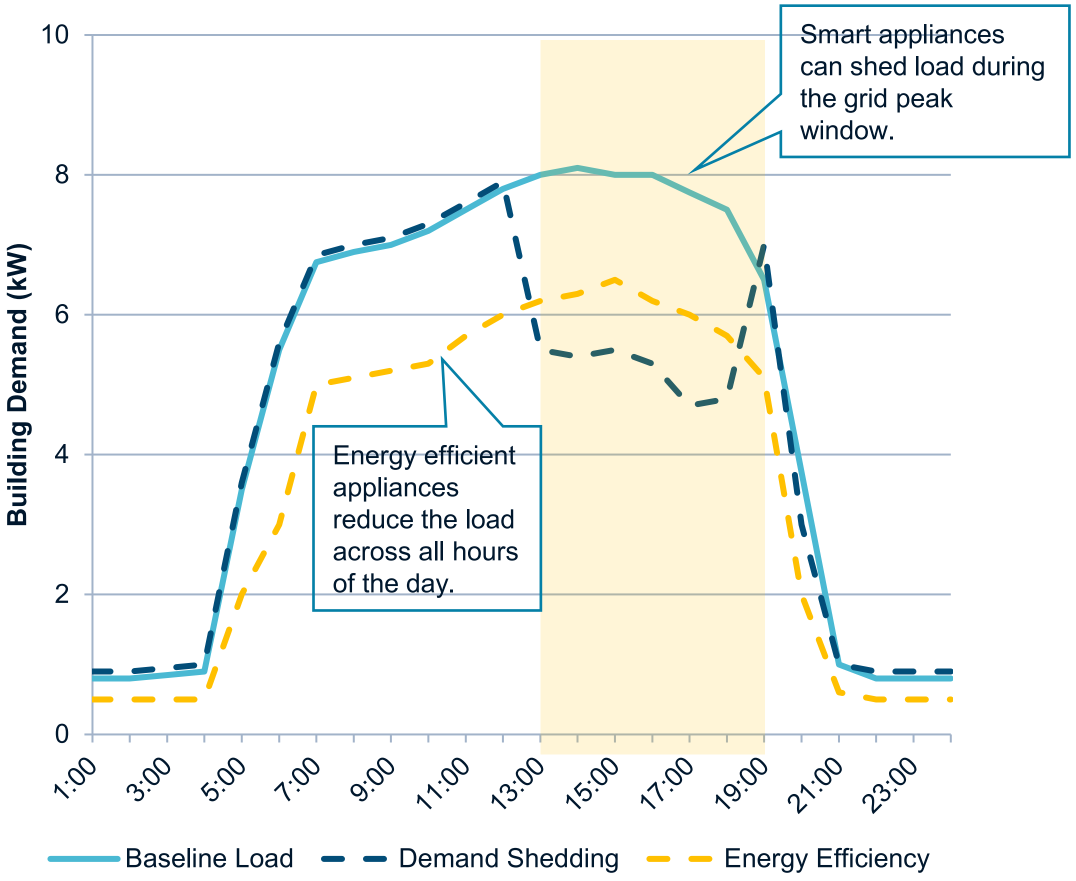


Source: PA Consulting 2024

[1]Source: There are many different ways to design such a Flexible Air-conditioning program, one of which is pre-cooling and reducing load during peak hours, or cycling the AC on and off across a large portfolio of customers (e.g., every 15 or 30 minutes) to manage the peak demand.

Standards, codes and engagement with utilities and the public are needed to leverage the potential of residential grid flexibility

Illustrative example of load shifting and load shedding to reduce the system peak demand



- **Building codes** for new construction and renovations to continue to encourage electrification for appropriate use cases, including continued work with International Code Council
- Standardized **communication protocols** for devices that simplify communication with grid
- Scaling up programs in **partnership with utilities** to ensure that customers can benefit from participation in events or ongoing grid flexibility initiatives as well as innovative rates
  - Many utilities and private entities (e.g. OhmConnect, EnergyHub) offer demand response programs, but uncertain participation rates
  - 72% of meters are smart meters, but only 14% of utilities offer TOU rates and an even smaller number of customers are actually enrolled.
- Flexibility must be automated so that individuals can easily maximize potential of reducing and shifting load and minimize impact on their lives. Continued **communications and public relations** is needed to increase adoption of devices, rates and incentives, changing habits and enhance general comfort with participation with the grid.

Source: PA Consulting 2024

Appendix iv: Glossary & Data Links

- Definitions for acronyms used throughout the study
- Links to referenced data and studies

Glossary of key terms

Term	Definition	Term	Definition
AMI	Advanced metering infrastructure.	Energy Arbitrage	The practice of purchasing electricity when prices are low and then storing or reselling it when prices are higher.
Ancillary Services	Services necessary to support the transmission of electric power from generators to consumers given the obligations of control areas and transmission utilities within those control areas to maintain reliable operations of the interconnected transmission system.	Energy Efficiency	The use of less energy to perform the same task or produce the same result either through 1) deployment of electricity energy efficiency utility programs that encourage consumers to use more energy efficient assets / appliances and/or 2) through improved energy efficiency by switching from molecule fueled assets / appliances to electricity powered ones.
BTM	Behind the customer electricity meter.	Grid Flexibility	The capability of the power system to maintain balance between generation and load under uncertainty.
CAGR	Compound annual growth rate (CAGR) measures an investment's annual growth rate over a period of time.	IBEW	International Brotherhood of Electrical Workers.
Electricity Generation Capacity	The amount of electricity a generating asset can produce when it's running at full blast.	ICE	Internal Combustion Engine.
Coincidental Peak Demand	The energy demand of a customer or group of customers at the time of the electric or gas system's peak demand.	LDV/MDV/HDV	Light / Medium / Heavy duty vehicles – classification of road vehicle types.
Demand	How much electricity is being used / predicted to be needed at any given time.	Load	In electricity load forecasting means In load forecasting means demand (in kW) or energy (kWh).
DER	Distributed Energy Resources – small-scale unit of power generation that operates locally and is connected to a larger power grid at the distribution level - including solar panels, small natural gas-fueled generators, electric vehicles and controllable loads, such as HVAC systems and electric water heaters.	MISO	Midcontinent Independent System Operator, Inc.is an Independent System Operator (ISO) and Regional Transmission Organization (RTO) operating in the central parts of the USA.
DERMS	A distributed energy resources management system (DERMS) is a platform which helps mostly distribution system operators (DSO) manage their grids that are mainly based on distributed energy resources (DER).	Net Consumption	Consumption of electricity computed as overall demand for electricity consumption, minus local BTM resources energy use and impact of energy efficiency.
Dispatchable Supply	Sources of electricity that can be programmed on demand at the request of power grid operators, according to market needs.	Net Load	Generation of energy injected into a specific electrical system, plus energy received from other systems less energy delivered to other systems.
DOE	Department of Energy.	NYISO	New York (State) Independent System Operator.
ELCC	Effective Load Carrying Capability (ELCC) measures a resource's contribution to reliability based on the incremental quantity of load that can be satisfied by adding the resource to the grid.	TFE	Total Final Energy is the aggregate of all the end use energy that is used for providing various energy services. This means that this total focuses on energy currencies like electricity and secondary fuels like gasoline.
Energy	Power derived from the utilization of physical or chemical resources, especially to provide light and heat or to work machines.	V2G	Vehicle to Grid.