GALVANIZE
CLIMATE SOLUTIONS

Grid-Flexibility is the Key for Decarbonization

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Introduction

The electrical grid is the key technology for enabling economy-wide decarbonization.

Recent analysis of 177 net zero scenarios[1] shows electricity's share of final energy demand increasing from 20% today to ~50% when net zero is achieved (Exhibit 1). This trend is consistent across regions and per capita energy consumption levels, highlighting the global importance of clean electricity delivered via a robust, reliable grid.

To decarbonize the global economy, the electricity grid must address two major challenges:

1. Decarbonizing existing electricity generation
2. Expanding to meet new demand from electrification of buildings and transportation alongside increased demand from the onshoring of manufacturing and the growth of AI

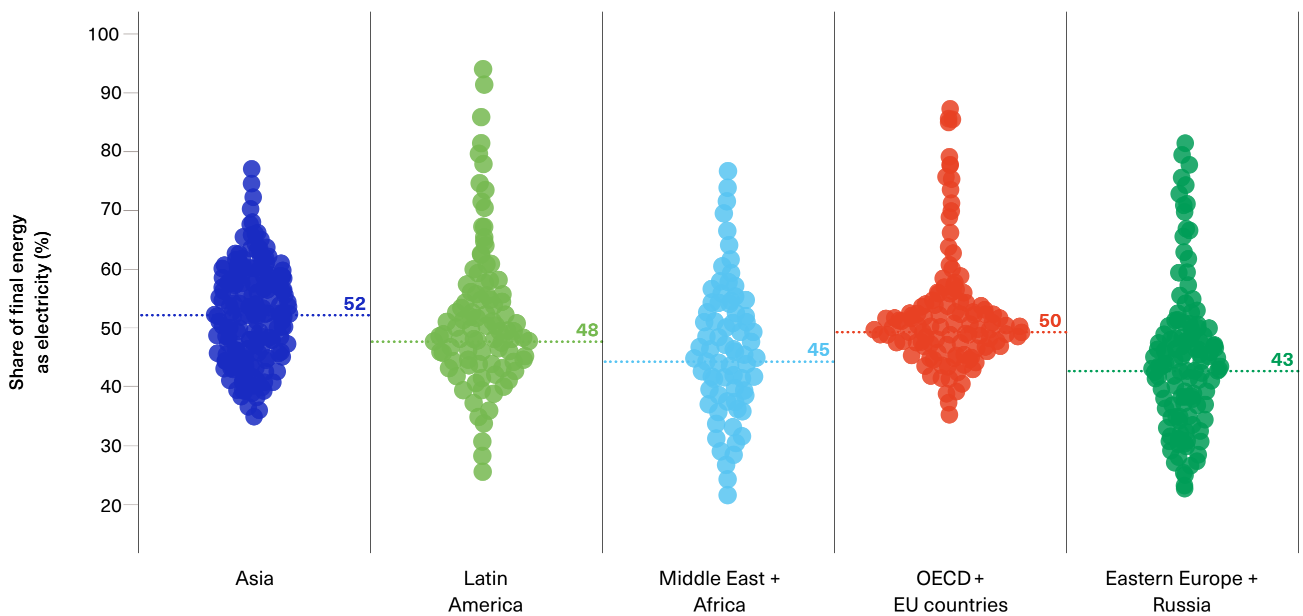
These challenges require widespread deployment of variable renewable energy (VRE, e.g., wind and solar), which has significant consequences for grid composition. Principally, VRE deployment necessitates flexible solutions to fill generation gaps (when the sun isn't shining or wind isn't blowing), new transmission solutions to connect new generation assets to the grid, and improved forecasting tools that tie weather data into grid operations.

→ A changing paradigm: Load growth in the U.S.

After nearly two decades of low-to-no demand growth, the U.S. grid is experiencing significant load growth driven by 1) the electrification of transportation and buildings, 2) the onshoring of manufacturing, and 3) growth in demand for compute (primarily for generative AI). Many estimates expect growth to approach or exceed 2.5% annually through 2030[2]. Critically, this load growth is not spread evenly throughout the day or year, driving massive spikes in what is known as "peak demand". To cover this future peak demand, many utilities in the U.S. will require installed generation capacity to be 2 to 3X greater than it is today (e.g., Exhibit 2).

Exhibit 1. Percentage of Final Energy Served by Electricity in Net Zero Scenarios, by region[1]

Note: The dashed line represents the median value.



1. **Source:** J. DeAngelo, et. al., Energy systems in scenarios at net-zero CO2 emissions, Available: https://www.nature.com/articles/s41467-021-26356-y#:~:text=Although%20electrici-ty%20makes%20up%20a,2c.
2. As one example, see Goldman Sachs, "AI is poised to drive 160% increase in data center power demand", Available: https://www.goldmansachs.com/insights/articles/AI-poised-to-drive-160-increase-in-power-demand

Expected load growth varies geographically, with some regions facing increases in total power demand of over 5% per annum. For example, manufacturing re-onshoring is concentrated in the Midwest and Southeast, while data center growth is focused on areas like Northern Virginia, Phoenix, and Chicago (Exhibit 3).

→ The growth of VRE is upending traditional grid operation

80% of electricity generation capacity installed in the U.S. in the past 3 years has been VRE, predominantly solar photovoltaics (PV) and onshore wind[3]. This trend is expected to continue, resulting in up to a 5x expansion of total grid-connected capacity by 2050 in net zero scenarios[4] - presenting both a historic investment opportunity and an unparalleled infrastructure development challenge if this is to be accomplished on a timeline consistent with limiting warming to 1.5C or 2C. *A grid with significant VRE capacity requires an overhaul of traditional operating paradigms*. Instead of constant baseload generation with dispatchable natural gas plants servicing spikes in demand, the future grid must absorb VRE generation when available while filling lulls in supply with technologies that can deliver power instantaneously and ramp up/down with weather variations.

The increased reliance on VRE, combined with load growth, creates three critical opportunity spaces for grid solutions:

1. **Generation Smoothing Solutions:** Flexible solutions to smooth out VRE electricity generation
2. **Transmission Enhancement:** New solutions that deliver more electricity along new and current transmission corridors from VRE-rich areas to load centers
3. **Grid Operations and Planning:** Tools to better incorporate weather data for load and generation forecasting and grid operations

Exhibit 2. Northern Indiana Public Service Company (NIPSCO) forecasted peak load by demand source, 2024-2043[5]

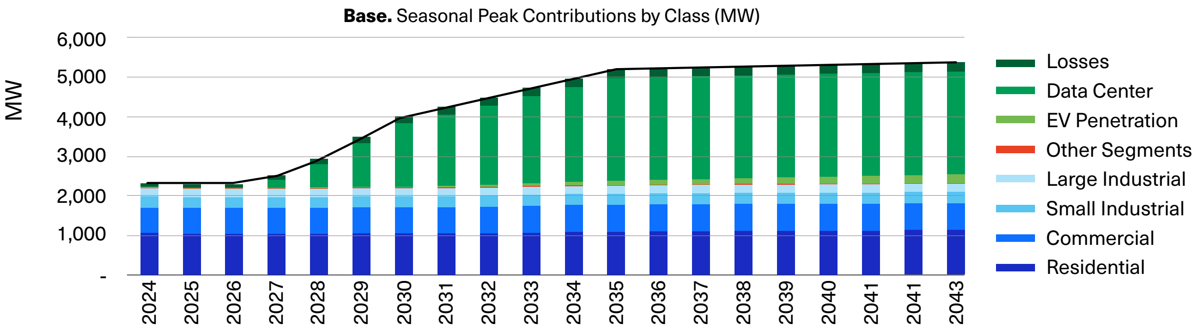


Exhibit 3A. Cumulative announced new manufacturing facility investment >$1B since passage of IRA (as of Dec. 2023)[6]

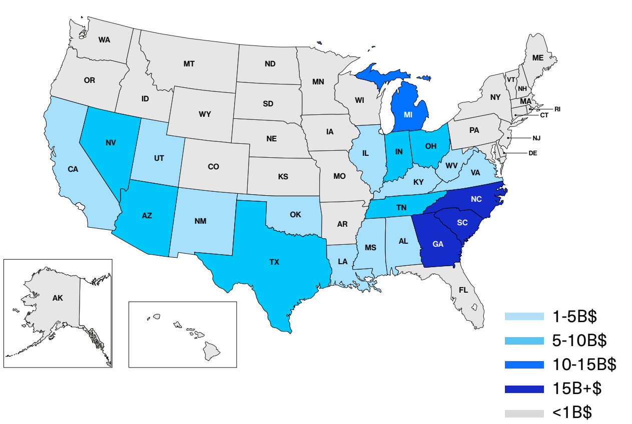
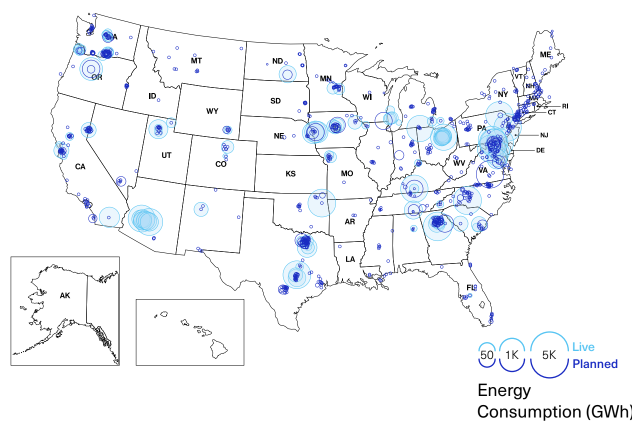


Exhibit 3B. Current and forecasted (2030) electricity demand from data centers in the U.S.[7]



3. **Source:** EIA, Form EIA-860 detailed data, Available: https://www.eia.gov/electricity/data/eia860/
4. As one example, see EPRI, LCRI Net-Zero 2050: U.S. Economy-Wide Deep Decarbonization Scenario Analysis, Available: https://www.epri.com/research/products/000000003002024993.
5. **Source:** NIPSCO, 2024 NIPSCO Integrated Resource Plan: Second Stakeholder Advisory Meeting, Available: https://www.nipsco.com/docs/librariesprovider11/rates-and-tariffs/irp/2024-irp-stakeholder-advisory-meeting-2-final.pdf?sfvrsn=3131e151_6.
6. **Source:** Manufacturing Dive, Tracking the Inflation Reduction Act's impact on US manufacturing, Available: https://www.manufacturingdive.com/news/inflation-reduction-act-tracker-clean-energy-manufacturing/715116/.
7. **Source:** Bloomberg, "AI is Already Wreaking Havoc on Global Power Systems", Available: https://www.bloomberg.com/graphics/2024-ai-data-centers-power-grids/?cmpid=BBBXT062424_ENERGY&utm_medium=email&utm_source=newsletter&utm_term=240624&utm_campaign=energy.

2 Opportunity 1: **Generation Smoothing Solutions**

To adequately smooth gaps in VRE production, flexible generation is needed to cover various time durations including Daily (<8 hours) and Long Duration (8 – 100 hours).

→ Daily (<8 hour) Flexibility

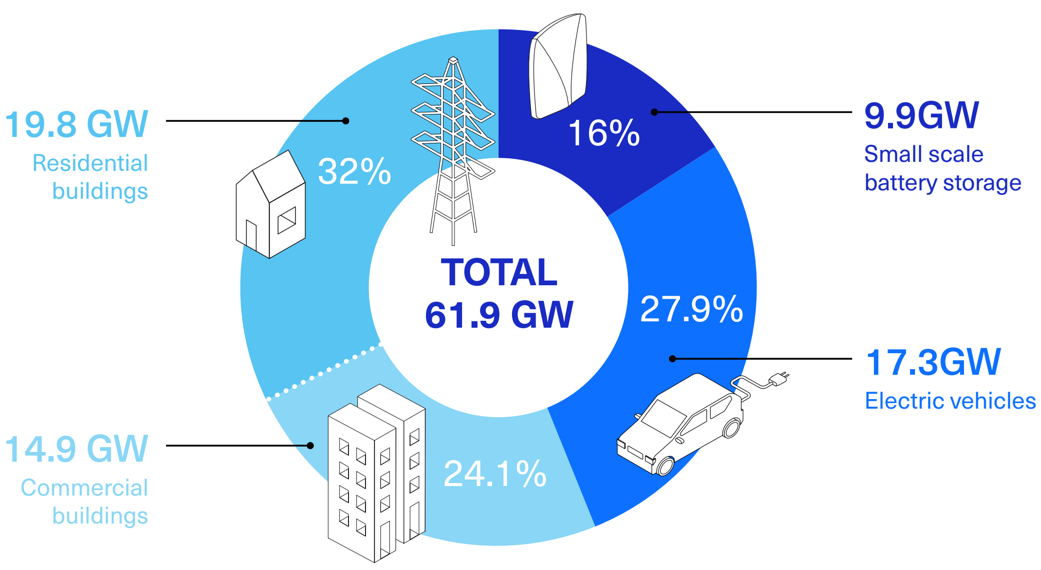
Daily flexibility fills gaps between renewable production and demand each day. Solutions must have rapid response capability, as a solar plant's output can change by >50% in less than a minute. Battery storage is the most common solution, but virtual power plants (VPP) and demand response (DR) also can play a role.

The current structure of electricity markets – where energy delivery makes up >90% of revenue, while ancillary services and capacity payments capture relatively little value – results in a situation where daily flexibility solutions capture most of the value available to any form of solution. Recent analysis of a market structures similar to that of California found that 4-hour storage systems captured 84-88% of the value available to any storage asset[8]. Additionally, the growth in solar PV installations results in PV meeting all of the electricity demand during the middle of the day in many locations (e.g., the Duck curve). This then requires in the need for coupling of solar PV installations with 2-4 hour battery energy storage systems (BESS) to ensure any individual, new installation can supply power without being curtailed.

There are two forms of solutions that can service the daily flexibility need:

- **Daily Storage:** BESS dominates this market. Galvanize believes key characteristics of the best solution in this market include low CAPEX and high round-trip efficiency (RTE). Lithium-ion technology leads in this market, with sodium-ion batteries emerging as a potential competitor. Galvanize believes that electrochemical BESS technologies such as these are effectively "locked-in" as the solution for daily storage for the foreseeable future.
- **Virtual Power Plants (VPPs):** These consist of aggregated household appliances (e.g., thermostats, water heaters, and

Exhibit 4. Potential VPP capacity in the U.S. by 2030[9]



8. **Source:** NREL, Moving Beyond 4-Hour Li-Ion Batteries: Challenges and Opportunities for Long(er)-Duration Energy Storage, Available: https://www.nrel.gov/docs/fy23osti/85878.pdf
9. **Source:** RMI.

heat pumps) and distributed energy resources (DERs, e.g., rooftop PV, residential BESS) to provide grid services. VPP potential is expanding due to increased connectivity and DER adoption (Exhibit 4), however challenges in balancing the value VPPs provide (and therefore the payment consumers receive) against the increased depreciation of equipment and the value consumers place on total control of the operation of their devices must be addressed to unlock the full potential of VPPs.

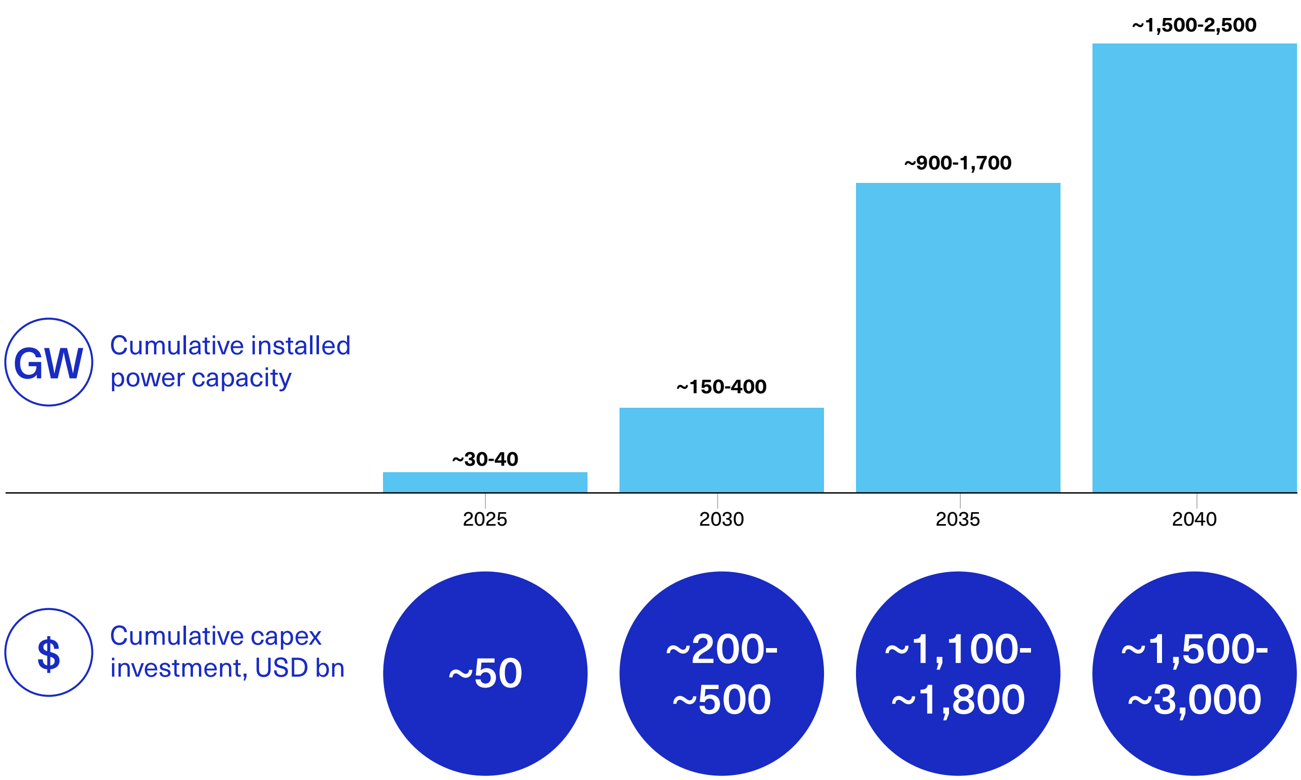
→ Long Duration (8-100 hour) Storage

Week-to-week variations in VRE output create a need for longer-term storage solutions. These do not require the rapid response of daily flexibility solutions, but capital costs are crucial to manage due to less frequent utilization. Additionally, RTE is still important in comparing long duration solutions, but its importance is diminished relative to daily flexibility solutions.

Current market structures challenge long duration energy storage (LDES) financial viability. Low RTEs for these solutions prevent them from competing to deliver, and therefore capture the value of daily flexibility needs. Without significant market reforms - such as higher capacity payments with longer duration requirements - Galvanize believes the primary deployment opportunity for LDES is rate-basing (i.e., utility ownership and operation compensated outside of electricity markets). Further, we believe regulators will be unlikely to approve rate-basing a large amount of CAPEX intensive, infrequently utilized LDES technologies, limiting their growth. However, should LDES friendly reforms be made, industry estimates that there will be a sizeable market for LDES technologies (Exhibit 5).

Current LDES solutions include established technologies like pumped storage hydropower (PSH) and concentrating solar power (CSP) with thermal energy storage (TES). However, these technologies face geographical and environmental limitations. These limitations have created an opportunity for emerging technologies such as flow batteries, liquid air energy storage (LAES), adiabatic compressed air energy storage (CAES), liquid CO_2 storage, and standalone TES. While some cost and performance results and estimates for these technologies exist[10], they are largely based upon pilot-scale demonstrations and it is too early to identify any clear best solutions in this space.

Exhibit 5. Estimate of demand for LDES[11]



10. For example, see Lazard, LCOE+ 2023, Available: https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/.

11. Source: LDES Council, Net-zero power: Long duration energy storage for a renewable grid, Available: https://www.ldescouncil.com/assets/pdf/LDES-brochure-F3-HighRes.pdf.

3 Opportunity 2: **Transmission**

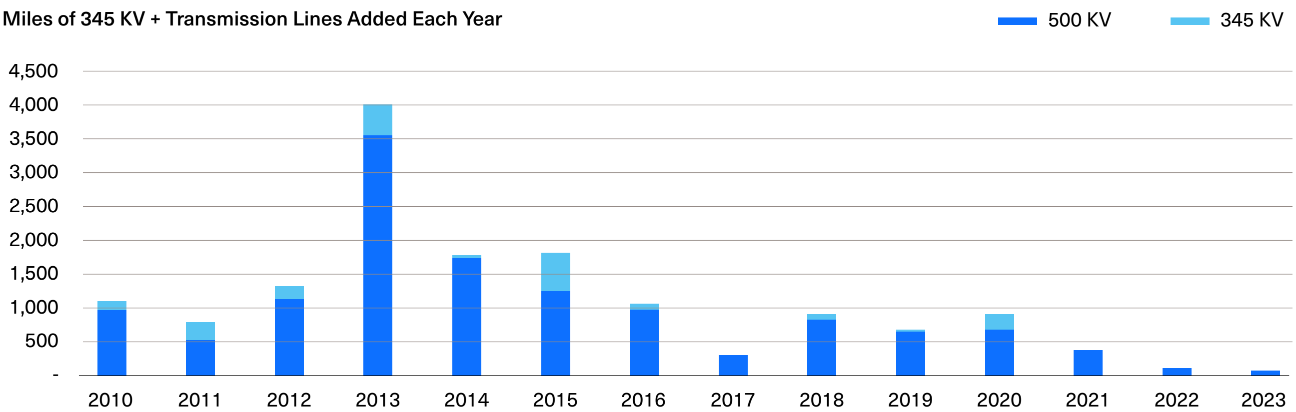
Increasing VRE reliance creates transmission challenges as the best renewable resources are often in unpopulated areas, require larger land footprints, and have lower capacity factors than fossil sources. Additionally, general load growth and increasing resiliency needs are already further increasing demand for additional transmission.

Despite this recognized need, the construction of high voltage lines in the U.S. hit a multi-decadal low in 2023 (Exhibit 6). While there is increasing political will to address the need for more transmission, the combination of lengthy permitting and construction times (often >10 years), local and environmental pushback, and limited land availability into population centers creates a need to find solutions that can expand and more efficiently utilize the existing transmission right-of-way to enable continued expansion of VRE deployment.

Recent DOE projections show a need for regional transmission (i.e., low- and medium-voltage) to expand by up to 128% and interregional transmission (i.e., high-voltage) to expand by up to 412% by 2035. The value of transmission is also increasing (in some cases to above $40/MWh), especially in wind-rich areas where electricity is being curtailed[12].

In the U.S., how transmission is built is increasingly complex. The first source of complexity is the changing utility model. In some states large utilities have been forced to become "wires-only", meaning that they largely only own transmission and distribution assets. They are compensated on a rate basis, however, meaning they are not incentivized to build new transmission unless approved by the public utility commission at their regulated rate of return. Further, as transmission is their primary asset base, they are likely to push back on any proposed merchant transmission lines. In vertically integrated utility territories (i.e., the utility owns both generation and transmission assets), similar behavior largely holds true. Therefore, for most of the U.S. merchant transmission makes up a tiny fraction of total transmission (e.g., less than 1% in PJM[13]) and utilities are increasingly pushing for policies such as state mandates of first refusal rights on any new transmission construction, as has been done in Indiana[14] to maintain this control. Galvanize believes that policymakers should be pushing for more competitive market structures in the transmission landscape to reduce development timelines and cost.

Exhibit 6. High voltage transmission construction in the U.S., 2010 – 2023[15]



12. **Source:** DOE, National Transmission Needs Study, Available: https://www.energy.gov/sites/default/files/2023-12/National%20Transmission%20Needs%20Study%20-%20Final_2023.12.1.pdf.
13. **Source:** RFF, Transmission 102: Building New Transmission Lines, Available: https://www.rff.org/publications/explainers/transmission-102-building-new-transmission-lines/#:~:text=Most%20transmission%20in%20the%20United,return%20to%20the%20utility%20owner.
14. **Source:** Utility Dive, Indiana utilities gain 'right of first refusal' to build transmission lines amid MISO buildout, Available: https://www.utilitydive.com/news/indiana-utilities-right-of-first-refusal-rofr-transmission-miso-aes-duke/649164/.
15. **Source:** GridStrategies, Fewer New Miles: The US Transmission Grid in the 2020s, Available: https://gridstrategiesllc.com/wp-content/uploads/Grid-Strategies_Fewer-New-Miles-2023.pdf.

A second source of complexity has been the increasing regulatory burden around permitting new transmission. There has been bipartisan agreement on the need to reduce this regulatory burden – highlighted by the proposed bi-partisan Energy Reform Act of 2024 and the recent FERC Order 2023, which has a goal of reducing the Federal permitting process down to 2 years (from the current 3-5 year process). These efforts, even if successful, are unlikely to reduce the total time required to build new transmission below 5 years. This means that if new transmission were to service the DOE's 2035 projection need it would, at best, be necessary to start the planning process within the next 5 years and – absent successful reform - it may already be too late.

Given permitting challenges, Galvanize believes it is highly unlikely construction of new transmission capacity can match need – which is up to 5-10x the current historical build rate (Exhibit 7). Therefore, the solution for additional transmission is going to be technologies that grow existing capacity. These technologies include:

1. **Dynamic Line Rating (DLR):** Deploys on or near-line monitoring to allow real-time calculation of carrying capacity – as opposed to static calculations based upon basic material properties - potentially increasing line capacity by ~30%.
2. **Reconductoring:** Replaces existing wires with higher capacity conductors, increasing carrying capacity 2-10x depending on material and voltage. It is often quick to implement and a fraction of the cost of new build transmission (Exhibit 8).

Exhibit 7. Forecasted transmission need vs. Historical build rates[16]

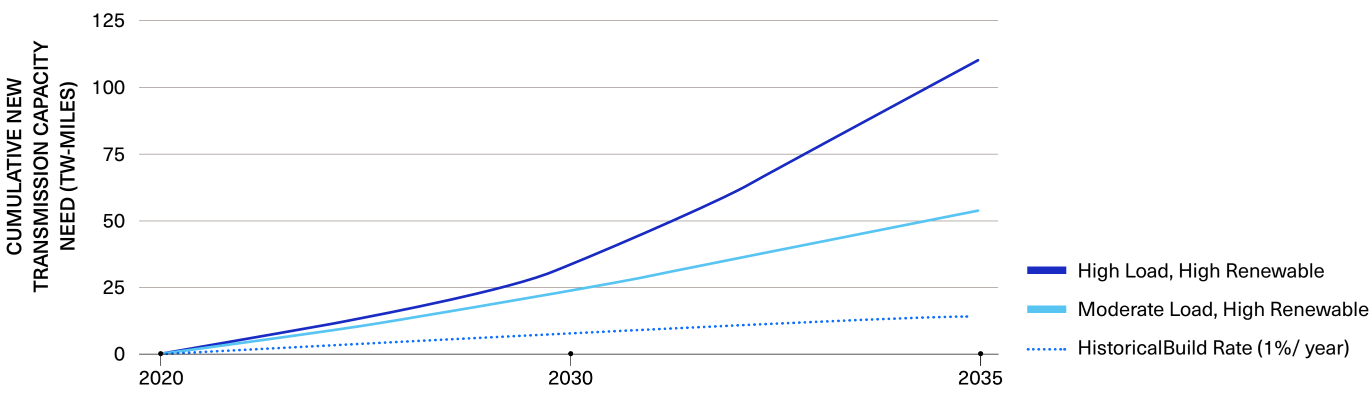
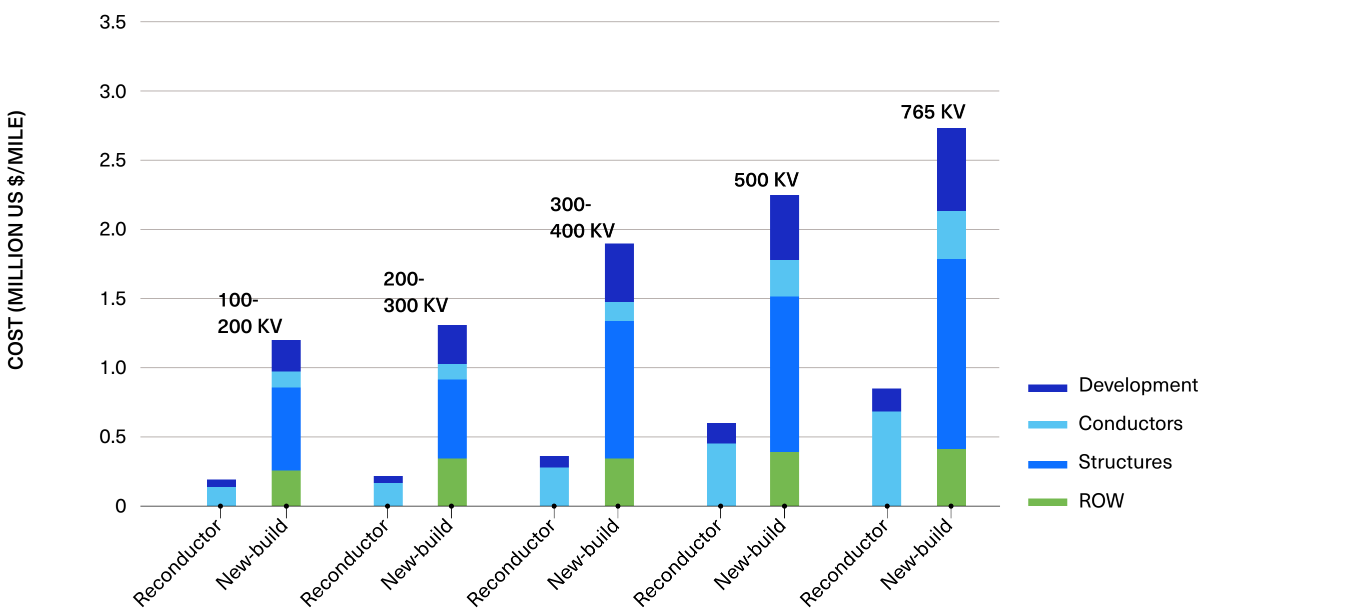


Exhibit 8. Cost estimates of reconductoring vs new build transmission[17]



16. **Source:** Gridlab, Supporting Advanced Conductor Deployment: Barriers and Policy Solutions, Available: https://www.2035report.com/wp-content/uploads/2024/05/5.3-Reconductoring-policy-report.pdf.
17. **Source:** Ibid.

4 Opportunity 3: **Grid Planning and Operations**

The transition to a VRE-dominated grid coupled with increased electrification makes grid planning and operations more complex and increasingly critical. Weather becomes the primary "fuel" for the grid, with weather events also being the primary driver of increased load variability and pricing volatility. Increasing VRE penetration – fueled by weather drives wholesale electricity pricing lower on average, but it also increases the volatility of pricing (Exhibit 9). This makes accurate production and pricing forecasts critical for utilities, independent power producers (IPPs), and businesses that own or purchase electricity sourced from VRE and BESS.

Historically, the market for grid operations and planning solutions was limited to utilities, grid operators, a small group of electricity traders, and large IPPs. Recent explosive growth in VRE assets and BESS has drastically expanded the number of parties in need of grid planning and operations software. According to BNEF data, there are now over 250 companies that own >100MW of solar and wind generation in the U.S. alone.

Grid planning and operations tools are used for a variety of applications – ranging from long-term system planning to daily electricity dispatch or trading. Two applications that are becoming increasingly important are 1) risk reduction for delivery obligations – be it for the virtual power purchase agreements (VPPAs) that define VRE economics today or to residential electricity customers – and 2) managing the dispatch of storage assets. The split between day-ahead and real-time pricing - often called the DART spread - is critical for VPPA counterparties as one party has typically sold electricity in the day-ahead and must procure any shortfalls or sell any excess in the real time. Similarly, Storage owners must decide if grid operators have secured sufficient or insufficient day-ahead supply to determine which market their capacity will earn the greatest return in. Exhibit 8 shows how inaccurate planning and forecasting of needs and prices in these markets can expose those that must participate in the DART markets to extreme swings in pricing over the course of just a few days.

Exhibit 9. Estimated wholesale price effects in U.S. electricity markets with VRE delivering 40-50% of electricity[18]

Wind: 30% wind & 10+% solar | **Balanced:** 20% wind & 20% solar | **Solar:** 30% solar & 10+% wind

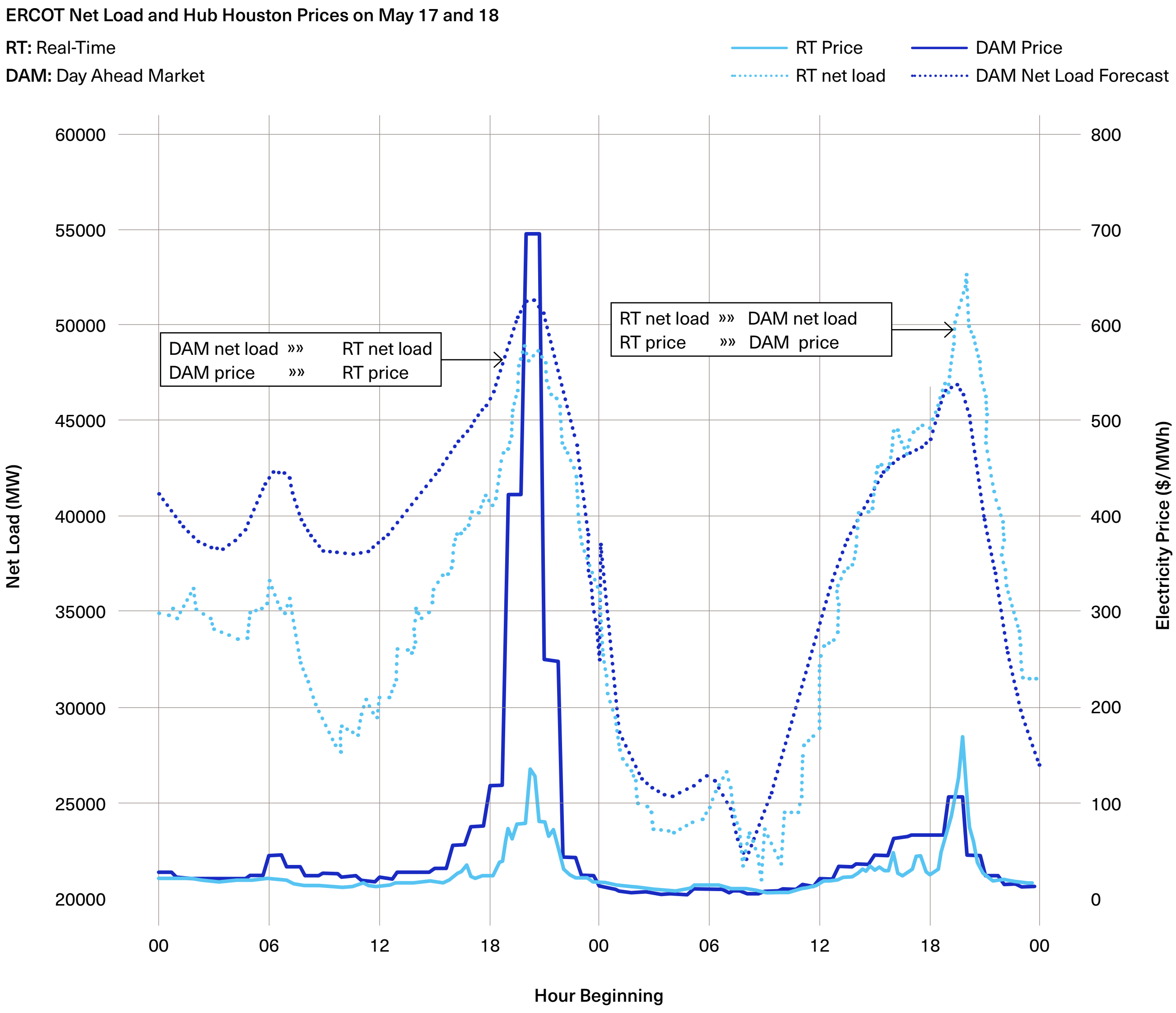
Impacts in 2030 relative to 2016 baseline	Southwest Power Pool			NYISO (New York)			CAISO (California)			ERCOT (Texas)		
	Wind	Balanced	Solar	Wind	Balanced	Solar	Wind	Balanced	Solar	Wind	Balanced	Solar
Lower Average Prices [$/MWh]	-19%	-21%	-27%	-37%	-38%	-39%	-25%	-23%	-27%	-25%	-17%	-15%
Increase in Price Variability	1.8x	2.1x	2.5x	2.1x	2.3x	2.5x	3.0x	2.9x	3.4x	1x	4.7x	6.6x
Increase in Ancillary Service Prices	5x	6x	9x	2x	2x	3x	3x	3x	3x	2x	3x	4x

18. **Source:** LBNL, Impacts of High Variable Renewable Energy Futures on Wholesale Electricity Prices, and on Electric-Sector Decision Making, Available: https://emp.lbl.gov/publications/impacts-high-variable-renewable

The solutions for grid planning and operation are typically software programs that service a single one of these needs, though there are some solutions that do both. Galvanize believes that the best solutions in this space are going to be the tools that can combine improved weather modeling with increased resolution of grid assets to arrive at more accurate operational needs and pricing forecasts.

1. **Planning Tools:** Production cost or capacity expansion models used for forward planning by utilities, IPPs, and industrial customers. These tools enable customers to answer questions about generation and transmission needs as well as identify best locations to connect new generating assets or load (e.g., data centers).
2. **Operations Solutions:** Solutions that provide insights into distribution system assets and operation, blending local grid physics with real-time and forecasted wholesale market pricing for asset dispatch decisions.

Exhibit 10. DART spreads at Houston Hub in ERCOT on May 17 & 18, 2024[19]



19. **Source:** Ascend Analytics.

5 Conclusion

The combined growth of VRE generation and electricity demand has created a significant opportunity for solutions that provide the flexibility the electric grid needs to play its critical role in decarbonization while continuing to deliver the affordable and resilient service consumers increasingly rely on.

- **Daily flexibility** needs are being addressed by Li-ion BESS solutions and VPP providers like GCS portfolio company Octopus, which operates a large VPP consisting of 207k customers with over 1.3GW of controllable load in the UK and Europe.
- **Long-duration flexibility** needs will be met by an emerging set of new technologies. Most of these technologies will require market reform to truly takeoff; however, GCS portfolio company Fervo is an example of the type of a decarbonized load following electricity generation technology that can fill this need while successfully operating within the current market environment.
- **Transmission capacity** expansion will rely heavily on upgrading existing infrastructure through DLR and reconductoring. Increasing the carrying capacity of the grid will require the utilization of novel resources and technologies like those offered by GCS portfolio company VEIR, whose conductors can carry up to 10X more electricity relative to traditional conductors.
- **New grid planning and operations solutions** are needed to optimally manage, physically and economically, an increasingly complex grid with resources that rely on the weather. There are many new companies attempting to address this space, but GCS portfolio company Ascend Analytics has been a leader in asset and grid optimization solutions and a leading provider of solutions for electricity storage owners and operators for nearly two decades.

The electrical grid is the key system for achieving a net zero future, with flexibility as the crucial requirement for new technologies incorporated into our 21st century grid. There is a wide array of flexibility needs providing a large market opportunity for new technologies that – outside of daily storage needs – are still being developed. GCS will continue to invest in the defining companies in the space to augment investments already made in Octopus, Fervo, VEIR, and Ascend Analytics because of the enormous positive impact these solutions will have on the climate and – critically – investor returns.

The electrical grid is the key system for achieving a net zero future, with flexibility being the crucial characteristic required for new technologies incorporated into our 21st century grid. There is a wide array of flexibility requirements providing a large market opportunity for new technologies that – outside of daily storage needs – are still being developed.

Exhibit 11. Mapping the grid flexibility ecosystem

Daily Flexibility

IPPs, Developers, & Integrators

aes, ALFEN, AMERESCO, Broad Reach Power, EDF renewables, ENGIE, FLEXGEN, FLUENCE, GENERAC, GE, GLIDEPATH, Invenergy, KEY CAPTURE ENERGY, LS POWER, NextEra Energy, res, SIEMENS energy, stem, TESLA, TOSHIBA, VISTRA, WÄRTSILÄ

Lithium-Ion Battery Manufacturers

24m, BYD, CATL, CB, EcoPro, EnerSys, ENPHASE, Envision AESC, GS YUASA, LG Chem, microvast, Panasonic, Powin Energy, MICROPOWER GROUP, SAMSUNG SDI, SMP, sonnen, ULTRALIFE, VARTA

VPP

octopus energy, FLUENCE, AutoGrid, BLUE PILLAR, BluWave-ai, Shell, MP2 Energy, David Energy, GENERAC, enel x, qcells, leap., Logical Buildings, GE, voltus, ABB, AMPERE ENERGY, Energy Pool, Enervalis, ENPHASE, GridBeyond, gridX, KALUZA, limejump, Lumenaza, origami energy, PEEEKS, centrica, SIEMENS, stemy energy, sympower, tiko, VATTENFALL

LDES

Mechanical

Compressed Air: Apex CAES, Cheesecake Energy, GREEN-Y, HYDROSTOR

Liquid Air: Highview Power, INNOVATIUM

Liquid CO2: ENERGYDOME

Gravity-Based: ares, ENERGY VAULT, ENERGYBANK, gravitricity, GRAVITY POWER, RENEWELL

Pumped Hydropower: RheEnergise, Quidnet Energy, MINE STORAGE

Electrochemical

Metal-Air: Form energy, ENZINC, ABOUND

Novel Chemistry: Ambri, ENERPOLY, eos, e-zinc

Flow Battery: cellcube, ENLIGHTEN, ESS, H2, INVINITY, NOON ENERGY, PRIMUS POWER, redflow, RFC POWER, SINERGY flow, VOLTSTORAGE, VRB ENERGY, XL Batteries

Thermal

Latent Heat: STORWORKS

Sensible Heat: 1414 Degrees, BRENMILLER, BUILD TO ZERO, EnergyNest, hyme, KRAFTBLOCK, KYOTO, MALTA, MGA THERMAL, SaltX

Transmission

Dynamic Line Rating

LAKI POWER, Ampacimon, prisma photonics, Splight, Infravision, LINEVISION, neara, Heimdall Power, windsim POWER, Grid Raven, LINDSEY SYSTEMS, SENTRISENSE, TOPOLONET, enline

Advanced Conductors

TS CONDUCTOR, GRIDWRAP, VEIR, Advanced Conductor Technologies LLC, EMROD, CTC GLOBAL, WTEC, Nano AL, METOX, ASSETCOOL

Grid Planning and Operation

Grid Planning

sensat, Transcend, kevala, envelio, Pearl Street, encoord, Bynry, Nira, xfmr.ai, HITACHI Inspire the Next, GRIDBRIGHT, RHIZOME, volue, Ascend Analytics, Energy Exemplar, GE, SIEMENS

Grid Operations

octopus energy, ThinkLabs, reactive technologies, Zaphiro, BSI, SENSEWAVES, Schneider Electric, ENERYIELD, WIA, NetworkEDGE, COGNITE, SIEMENS, GridQube, NovoGrid, ResilientGrid, PingThings, GE, LINIA, vividgrd., Ascend Analytics

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