Hitachi Energy

Strengthening grid technology supply chains to support the energy transition

Position Paper

HITACHI

01 Executive Summary

Electricity demand is surging across most major economies, driven by factors such as electrification of heating and cooling, transport and industry, as well as AI-driven data center expansion. In parallel, there has been an unprecedented increase in renewable power generation capacity installed in recent years. The changing nature of these generation and load profiles has placed the power grid in the spotlight. Long grid connection queues combined with curtailments due to grid congestion highlight that despite increased grid investment, the expansion and modernization of the power grid is not keeping pace.

Historically, grid development followed relatively predictable loads and centralized generation profiles. The current supply and demand evolution combined with projections for grid development has introduced an unprecedented level of complexity. In addition, all power systems are shaped by their own specific characteristics: constraints and priorities differ widely depending on geography, resource endowment, and the maturity and structure of the underlying energy market.

Regardless of the market, realizing current grid development and modernization ambitions will rely on a combination of factors, including adequate investment, faster permitting and regulatory approvals, the rapid deployment of grid technologies, and agile and resilient grid technology supply chains. While these challenges must be addressed, this position paper focuses specifically on the critical role of grid technology supply chains - examining why they are now a priority for power system evolution and the overall energy transition.

The surge in demand for grid technologies has outpaced global manufacturing capacity, leading to longer lead times for delivery of key technologies. Beyond manufacturing capacity constraints, additional challenges include volatile and supply-constrained markets for critical input materials such as copper, aluminum and electrical steel; transport and logistics challenges; as well as skilled workforce shortages.

Nevertheless, these challenges are manageable with the right actions. This position paper sets out recommendations to address current grid technology supply chain challenges.

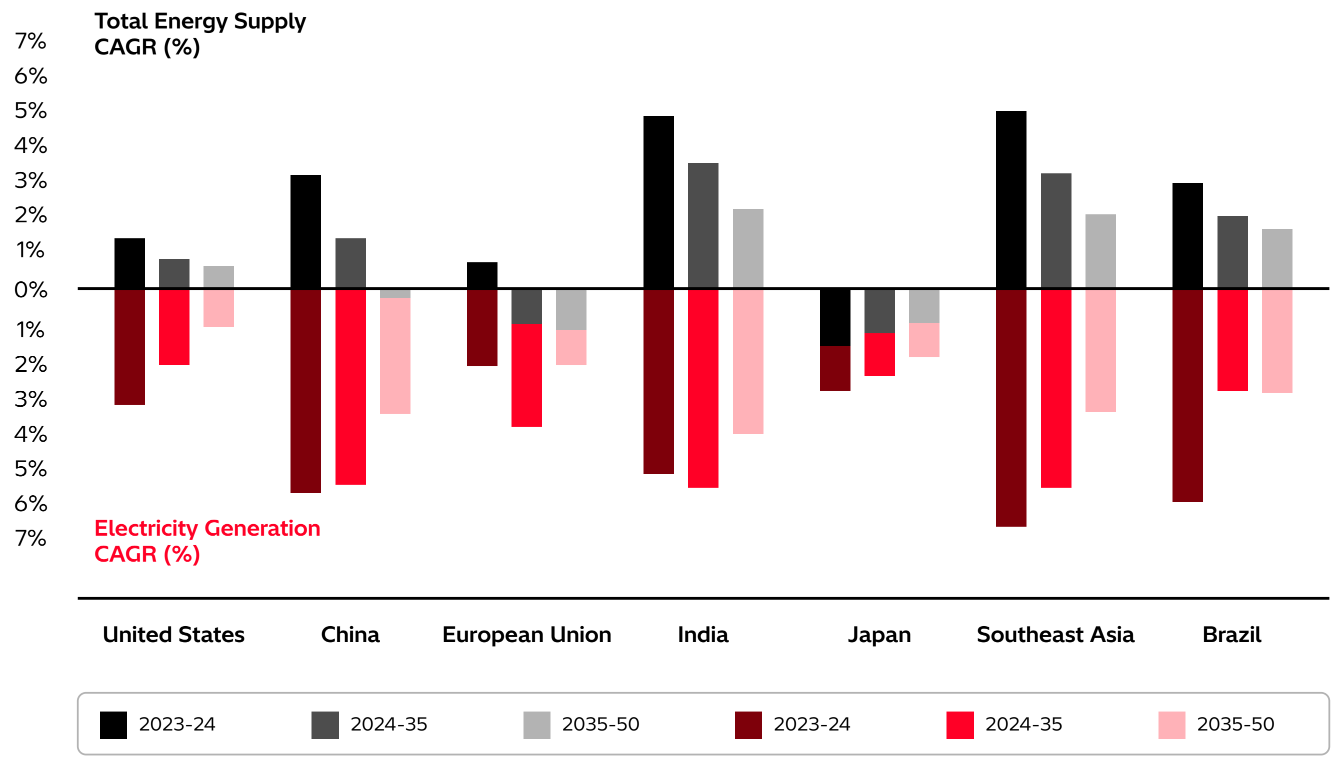
Key recommendations include:

- Implement longer term, integrated, coordinated and holistic planning.
- Develop and maintain agile and resilient grid technology supply chains.
- Enable innovative business models and supportive regulations.
- Enhance resilience of land, sea and air infrastructure.
- Adopt standards and implement standardization.
- Strengthen workforce development and technical talent pipelines.

02 Power grids in the "Age of Electricity"

The global power sector is entering a period of structurally higher electricity demand growth. Global electricity demand grew twice as fast between 2020–2025 compared with 2015–2020, a trend that is expected to continue in the near term[1]. In many markets, electricity demand is projected to grow faster than overall energy demand and gross domestic product (GDP). This marks a significant departure from past decades, when electricity demand growth was largely confined to emerging economies, while improvements in energy efficiency and industrial restructuring led to plateauing or declining demand in many advanced economies. This shift is driven by a diverse range of factors. Emerging economies continue to account for bulk of the growth in electricity demand, supported by improved access to electricity, economic expansion, industrialization, and lifestyle changes from rising income levels and adaptation to climate change. At the same time, macro trends such as accelerated decarbonization of the energy mix, electrification of buildings, transport, and industry, the rapid expansion of AI-related data centers, and increasing cooling demand - are expected to drive strong growth in electricity consumption including across advanced economies (as shown in Figure 1). In parallel, the geopolitical and geo-economic vulnerabilities exposed by recent fossil fuel market volatilities have reinforced the momentum behind electrification.

Electricity generation is projected to exceed growth in total energy supply across major economies

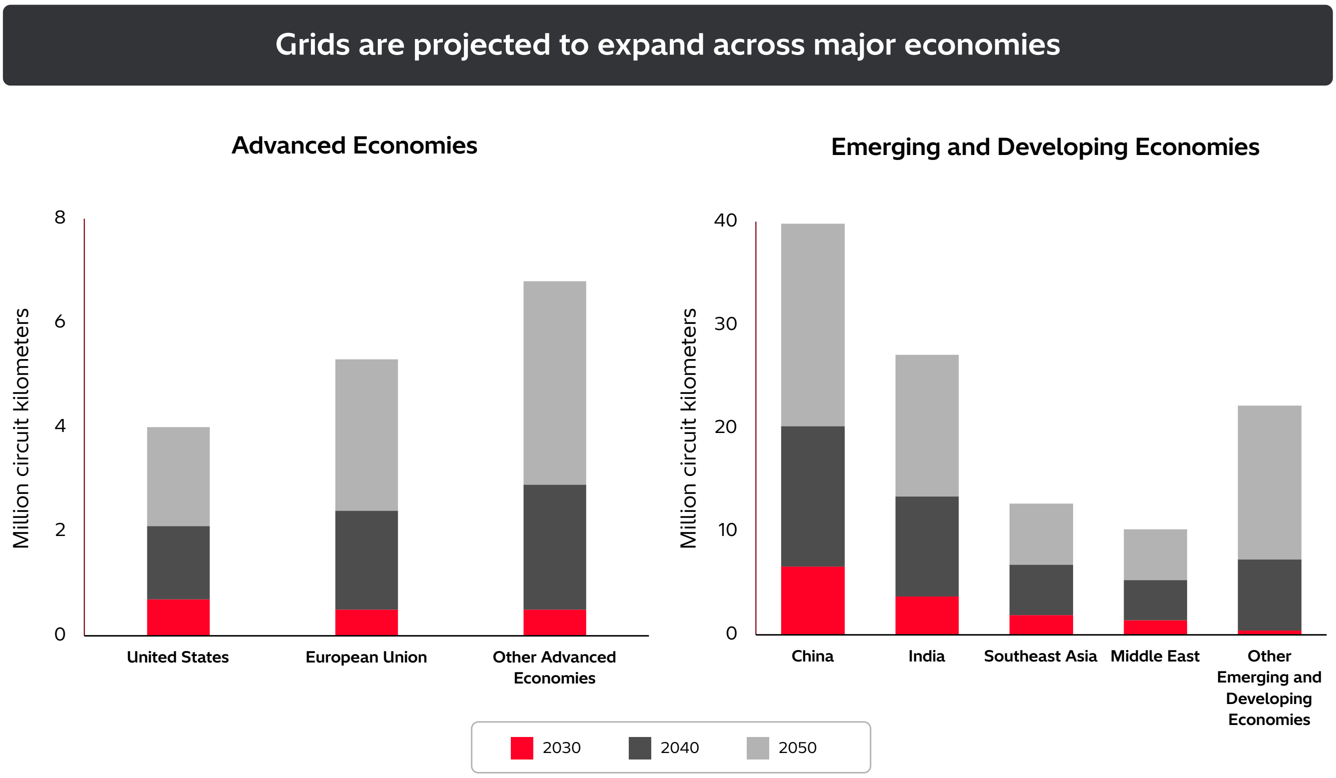


Note: Negative Total Energy Supply CAGR (%) values are superimposed on Electricity Generation CAGR (%) bars.

Forecasts based on IEA's Current Policies Scenario, which assume no change from current energy-related policies.

Figure 1: Energy supply and electricity generation growth trends are forecasted to diverge across multiple regions. Data source: IEA 2025; World Energy Outlook 2025, https://www.iea.org/reports/world-energy-outlook-2025, CC BY 4.0.

Beyond generation and end-use applications, the "Age of Electricity" has transformative implications for transmission and distribution grids. According to the International Energy Agency (IEA), and as shown in Figure 2, the world must add 65 million kilometers and replace a further 45 million kilometers of transmission and distribution lines by 2050[2]. The scalability of power grids is therefore increasingly becoming a key determinant of how quickly countries can electrify their economies.



Forecasts based on IEA's Current Policies Scenario, which assumes no change from current energy-related policies.

Figure 2: Grid expansion forecasts across regions (million circuit kms), Data source: IEA 2025; World Energy Outlook 2025, https://www.iea.org/reports/world-energy-outlook-2025, CC BY 4.0.

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Decades of under-investment in grids, slow and complex permitting procedures, fragmented and short-term approaches to grid planning and insufficient coordination across stakeholders have led to long grid connection queues and increased congestion. By 2026, over 2,500 GW of renewable, large-load and storage projects are awaiting grid connections globally[3]. Similarly, nearly half of data centers planned for 2026 in the US are expected to be delayed or cancelled[4].

In addition, the expansion and modernization of power grids depend on timely and sufficient availability of key technologies such as transformers, switchgear, cables, and conductors. Such technologies rely on manufacturing systems and material supply chains that are increasingly under strain.

Current grid equipment supply chains have evolved over decades and geographies, to serve a fundamentally different operating environment – one characterized by relatively stable investment cycles, driven primarily by predictable replacement demand and incremental network expansion. This position paper aims to identify the major constraints limiting the timely manufacturing and delivery of grid equipment, and to suggest recommendations to improve the agility and resilience of grid technology supply chain.

03 Grid technology supply chain challenges

Challenges to the scale up of the grid technology supply chain, some of which are being further exacerbated by geopolitical fragmentation and the upending of trade agreements, include:

Manufacturing capacity

The unprecedented nature of the demand surge, coupled with more than a decade of stagnant growth, has resulted in insufficient manufacturing capacity to meet grid development and modernization needs. As a result, lead times from order to delivery have increased across most electrical equipment categories, contributing to prolonged timelines for grid development, connection of generation sources, and commissioning of large industrial loads.

According to a recent survey by the IEA, lead times for large power transformers now average 2 - 4 years, and up to 4 years for DC cables used in long distance transmission. As a result, manufacturing slots for large power transformers and cables outside China are booked for 3 - 4 years[5] in advance. For example, according to Wood Mackenzie, demand for generator step up (GSU) transformers in the United States has increased by 274% since 2019, driven by rapid renewable deployment[6] (as shown in Figure 3).

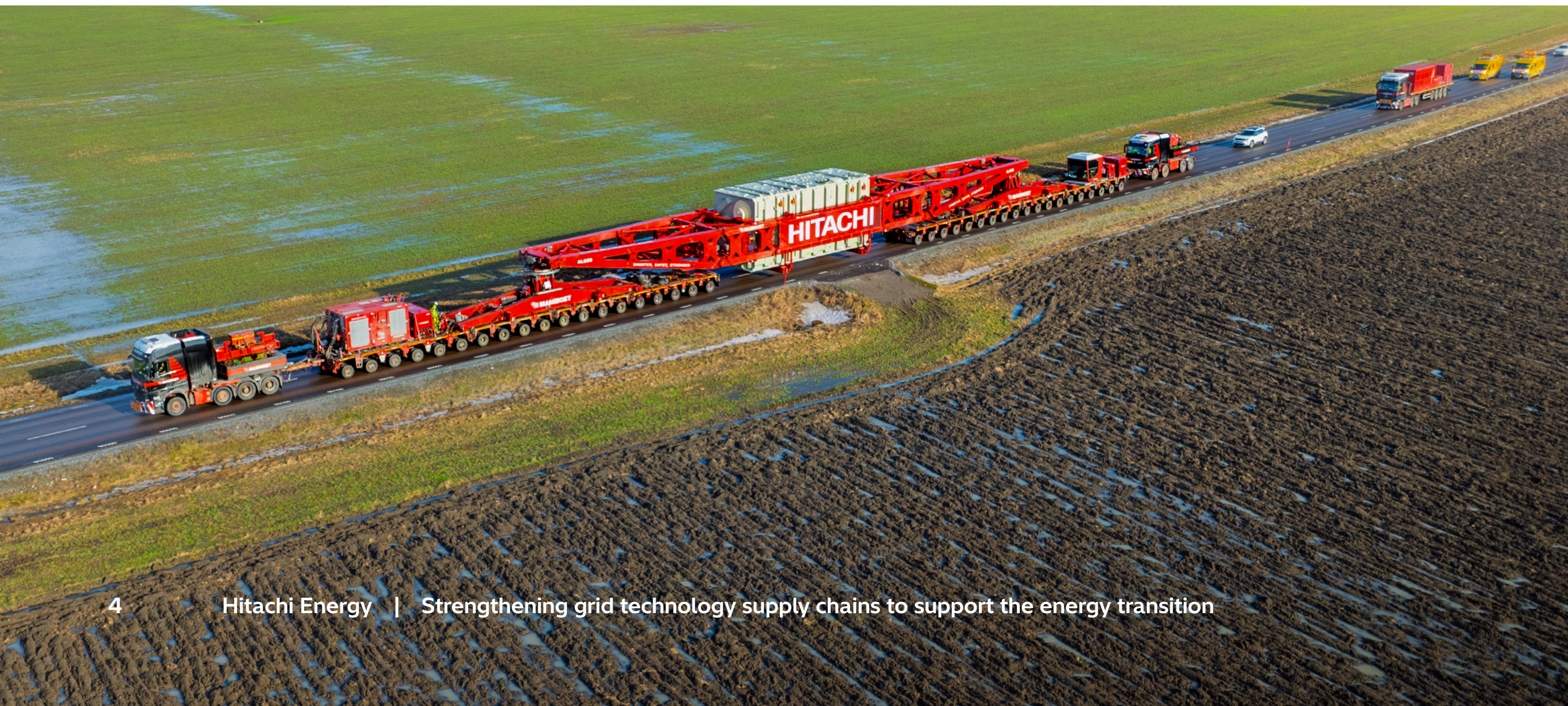
The grid equipment manufacturing industry has catalyzed significant investment in recent years to meet rising demand, with announced commitments of $1.8 billion[7] in the US in transformer manufacturing and €9 billion reported by T&D Europe[8] to expand capacity. While newly built and expanded facilities are already beginning to come online this year, the scale of demand means these additions will take time to relieve pressure, particularly as greenfield projects can take up to five years to complete and brownfield expansions up to three.

Critical materials

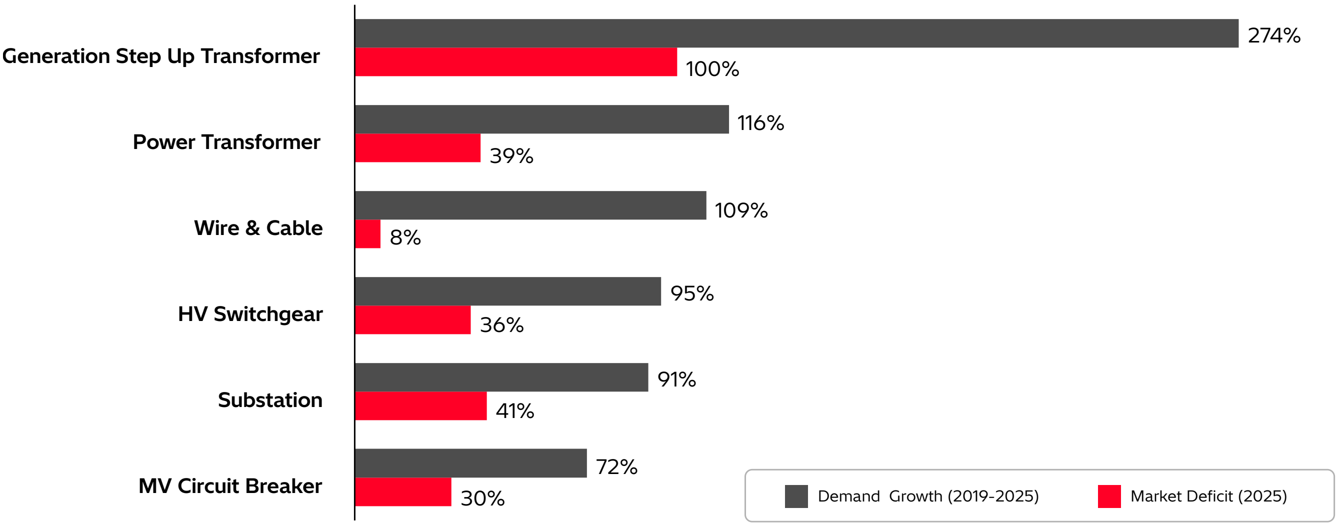
Critical material shortages and price volatility are emerging as key constraints on the speed of energy transition globally. Many power grid components - including transformers, switchgear and cables - are material intensive and rely on critical inputs such as copper, aluminum, and grain-oriented electrical steel (GOES)[9]. These materials are not only essential for performance but also account for a significant share of total equipment costs.

The recent surge in global electrification has increased demand for these materials, keeping prices elevated above pre-pandemic levels. At the same time, supply remains constrained by long lead times for mining and processing, geopolitical tensions, trade restrictions, and the concentration of production in a limited number of countries[10].

These dynamics introduce both cost uncertainty and supply risks for grid development and modernization. Higher input costs can delay investment decisions, while constrained material availability can extend manufacturing lead times and disrupt delivery schedules. Nonetheless, grid technology providers are actively securing access to critical materials in line with projected short- to medium-term build-out.



Grid equipment demand in the US has surged since 2019, contributing to market deficits



Market deficit: How much higher annual demand is than available supply.

Figure 3: Percentage increase in demand for different grid equipment categories in the United States between 2019-2025.
Source: Wood Mackenzie, 2025, Making the Connection: meeting the electric T&D supply chain challenge.

Transport and logistics

Whilst more of a short- to medium-term challenge, transport and logistics bottlenecks are also contributing to delays and cost increases in grid infrastructure projects. Transporting grid equipment requires specialized logistics systems capable of handling large, heavy components across remote and widely distributed locations.

For example, large power transformers can weigh hundreds of tons (two to three times heavier than the typical load of a railroad)[11], therefore requiring specialized processes and permits for travel. As demand increases, sufficient availability of specialized trains and transport infrastructure becomes critical. In some cases, transport routes may need to be upgraded to accommodate larger equipment specifications.

Similarly, the industry is facing a shortage[12] of cable laying vessels (CLV), which are required to move high-voltage cables from manufacturing to installation locations and to install them along pre engineered sub-sea routes, burying them for protection where needed.

Furthermore, global maritime supply chains are yet to fully normalize following the COVID-19 pandemic, and ongoing conflicts in key regions are further disrupting shipping routes, including the Red Sea and Strait of Hormuz passageways. Consequently, a higher-than-normal share of vessel traffic has been diverted through the Panama Canal[13] contributing to longer transit times and extended delivery lead times.

Skilled workforce

Surging electricity demand is also driving increased demand for specialized skills across the electricity workforce. Employment across the electricity value chain, including generation, transmission, distribution, and storage, has grown faster than both overall energy sector employment and the overall economy every year since 2019. As of 2024, the electricity sector employs approximately 22.6 million workers worldwide, with around one-third working in electricity grid related sub-sectors[14].

However, the sector also faces a significant shortage of skilled resources. Recently, 89% of US-based transformer manufacturers reported difficulties in finding experienced workers[15]. This is exacerbated by the long training cycles for specialized roles - up to four years to comprehensively train a large power transformer winder – as well as the location of manufacturing sites, which, while optimized for logistics, can limit access to skilled labor.

04 Targeted interventions can enhance grid technology supply chains

Addressing constraints in grid technology supply chains will require coordinated action across planning, procurement, industrial policy, and workforce development. While industry players are already taking steps to expand manufacturing capacity, broader support from policymakers and regulators is essential. It is vital from a supply chain perspective to have visibility on future demand and confidence among grid equipment manufacturers that this demand will materialize. These conditions are essential to enable suppliers to invest and deliver at scale.

Recommendation 1

Implement longer term, integrated, coordinated and holistic planning.

Fragmented and short-term planning leads to inefficient infrastructure development and limited demand visibility, discouraging investment in capacity expansion.

- **Extend grid planning horizons:** As power systems evolve to accommodate electrification, higher renewable penetration, and power electronics-based infrastructure, business-as-usual and incremental adjustments are no longer sufficient. Planning should be anchored in long-term (e.g. 2050) system scenarios.
- **Adopt holistic, integrated, and coordinated planning approaches:** Grid planning should incorporate aggregated demand projections across all major sectors, alongside generation development plans and industrial capacity capabilities, in alignment with broader national or regional energy transition strategies as well as local development plans. All relevant stakeholders should be actively involved through structured and ongoing coordination mechanisms. This includes better coordination between transmission and distribution operators through joint planning exercises. Functional requirements of the future grid - such as system stability services including reactive power and voltage support - must be systematically integrated into planning processes.
- **Shift towards strategic partnerships between grid developers and technology providers.** The relationship between technology providers and grid developers is evolving from transactional procurement towards long-term, strategic partnerships, where projects are increasingly co-developed. This shift enables earlier coordination across design, manufacturing, and delivery phases, improving supply chain visibility and overall efficiency. It also helps address structural constraints, such as workforce shortages, through better alignment of planning, resource allocation, and skills development. New frameworks and regulations are needed to further support this evolution, for example by enabling early-stage engineering and the procurement of long-lead materials ahead of final investment decisions.

Recommendation 2

Develop and maintain agile and resilient grid technology supply chains.

Continue to leverage global supply chains and free trade to the extent possible. An agile and resilient supply chain that can adapt quickly and withstand unforeseen disruptions is essential. Even as countries strengthen local manufacturing footprints, leveraging global grid technology supply chains, supported by free trade to the extent possible, continues to be critical. From a scaling perspective, it is not economically viable for countries to fully localize vertically integrated grid technology supply chains.

Increase local manufacturing footprints and build strategic reserves. With regional and domestic content requirements increasingly embedded in national industrial policy[16], grid technology providers are strengthening local supply chains even while continuing to leverage global supply networks. Expanding local manufacturing and reducing upstream dependencies - particularly for critical materials – requires a level of guaranteed demand for grid technologies in that region; transparent and accessible government incentives and policy measures; and enabling business models such as long term framework agreements. In addition, framing grid technology manufacturing within a national security context[17] can support targeted policies and incentives[18] to expand domestic production capacity and reduce exposure to geopolitical shocks[19]. Complementing these efforts with strategic reserves of critical components, based on harmonized designs and mutual assistance mechanisms between countries, can further enhance supply chain resilience.

Recommendation 3

Enable innovative business models and supportive regulations.

Accelerating grid development requires new approaches that enable grid developers to move at speed and scale while strengthening supply chains. Emerging business models can be scaled and replicated across regions, supported by long-term planning and enabling policy and regulatory frameworks. For example:

- **Anticipatory investments:** Traditional, reactive grid development tied to confirmed connection requests has led to connection queues across major markets. New approaches in the UK[20] and EU[21] enable grid operators to invest ahead of demand, supporting faster connection of both large loads and new generation.
- **Framework Agreements**[22] provide grid technology suppliers with multi-year, multi-project visibility, allowing them to scale production capacity and invest confidently in new manufacturing lines.
- **Capacity Reservation Contracts**[23] offer financial commitments for dedicated production slots, ensuring availability of slots during peak demand.
- **Shift from project to programs.** Moving from piecemeal project-by-project towards multi-project, program-based approaches can significantly accelerate grid development. This enables coordinated grid development, reduces administrative burden and supports scaling through replication. It also facilitates the use of models such as framework agreements and capacity reservation contracts, providing greater visibility and predictability for suppliers across the value chain.

Recommendation 4

Enhance resilience of land, sea and air infrastructure.

As supply chains scale and equipment sizes increase, transport infrastructure must keep pace. Large grid components such as transformers, reactors, and other high voltage equipment require specialized logistics and often place constraints on existing infrastructure. Inadequate transport capacity and lack of infrastructure can lead to delays or necessitate costly redesigns. Policymakers should ensure that supporting infrastructure such as railways, roads, airports and ports are developed and maintained to enable the efficient movement of large-scale grid equipment.

Recommendation 5

Adopt standards and implement standardization.

Adopt Standards: The use of standards helps ensure safety and interoperability. However, the benefits of standards can only be leveraged if they are widely adopted, and their proper use is verified through testing and certification. Policymakers could incentivize the use of these standards through referencing in legislation. Where possible, international standards should be prioritized.

Implement Standardization: Today, manufacturers face almost as many special design requests as there are projects. Implementing standardization to enable replicability between projects allows for the transfer of learnings, reduces design time, and results in more efficient manufacturing and construction, which can ultimately reduce project costs and timescales. Standardization can also help unlock the benefits of pooled procurement[24].

Recommendation 6

Strengthen workforce development and technical talent pipelines.

Scaling grid infrastructure requires a substantial expansion of specialized engineering, manufacturing, installation, and commissioning capabilities. Universities, technical institutes, and industry should collaborate to develop targeted training programs, complemented by vocational training, apprenticeships models, and reskilling initiatives to sustain long term industrial growth.

In addition, given that manufacturing facilities are often located outside major urban centers, supporting infrastructure, such as housing, public transport, schools, and childcare facilities, must be planned alongside industrial expansion to attract and retain skilled workers.

Conclusion

We have entered into the “Age of Electricity” and are becoming increasingly reliant on the electricity grid. Facing steep timelines for expansion and modernization, the ongoing grid buildout can be potentially delayed due to insufficient manufacturing capacity and other supply chain bottlenecks such as critical material availability, logistics and workforce. Without an efficient grid build-out due to long lead times for grid technology, critical power generation and new energy-intensive industrial facilities will continue to face delays coming on-line across major economies.

Building an agile and resilient grid technology supply chain is fundamental to sustaining societal well being, safeguarding economic competitiveness, and delivering national and global clean energy goals. Coordinated interventions across planning, procurement, industrial policy, and talent development, will help address equipment lead times and ensure that grid expansion catches up with accelerating electricity demand, enabling timely delivery of critical generation and industrial projects worldwide.

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Who is Hitachi Energy?

Hitachi Energy is a global leader in electrification, powering the electricity era to meet the energy demands of today, and the next 25 years. As the energy arm of Hitachi Group, over three billion people depend on our pioneering, mission-critical technologies to power their daily lives. With over a century of innovation, we are addressing the most urgent energy challenge of our time: driving the evolution of the world's energy system to ensure abundant, secure, affordable, and sustainable power for today's generation and the next.

With an unparalleled installed base in over 140 countries, we are the grid ecosystem partner across the utility, industry, data center, and transportation sectors. Headquartered in Switzerland, we employ over 56,000 people in 60 countries and generate revenues of around $20 billion USD.

Since 2020, the company has rolled out a $9 billion global investment program, the largest in the industry, to expand manufacturing, R&D, engineering, and partnerships to support the rapid growth in electrification and to make the world's energy system more sustainable, secure, resilient, and affordable.

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