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Whitepaper

The Solar Power System

Building a sustainable grid for a brighter energy future

Hitachi Energy

Why solar will keep booming in the US

Imagine it's 2050, and you just got out of your car. How do you imagine that experience? Your car might be fully autonomous, or even capable of flying – it would be quite difficult to predict. One thing is fairly certain, however – your car will be electric, and when it is plugged into the grid for charging, the electrons it receives will be greener than today. In fact, the International Energy Agency (IEA) expects overall US energy consumption to rise only 6% by 2050, but renewable consumption will experience an astronomical increase of more than 400% compared to 2022 levels.[1] Much of the anticipated increase in consumption will result from the rapid electrification of economic sectors historically dependent on fossil fuels, such as transportation, building heating and cooling, and process industries such as mining and metals, as well as accelerating demand from the growth of data centers.

The land of opportunity: Renewable energy in the US
Presently, renewable energy production in the US is largely dominated by solar photovoltaics (PV), onshore wind, and hydroelectric. The renewable segment has already made significant strides, accounting for about 13% of the US's total energy consumption in 2022.[2] This trend has accelerated over the last decade, with renewable generation expanding at a year-over-year growth rate of almost 11%.[3] This growth has been largely driven by falling technology costs alongside increased public and private support. Incentives such as investment tax credits (ITC) and production tax credits (PTC) have encouraged growth in renewable generation capacity.

Thanks to long-term, consistent government policies and subsidies such as those in the Bipartisan Infrastructure Law and Inflation Reduction Act (IRA), renewable generation is expected to continue to grow at a breakneck pace. Benefits from the IRA in the form of ITCs and PTCs are expected to continue until at least 2050, thus providing long-term financial certainty to the market.[4]

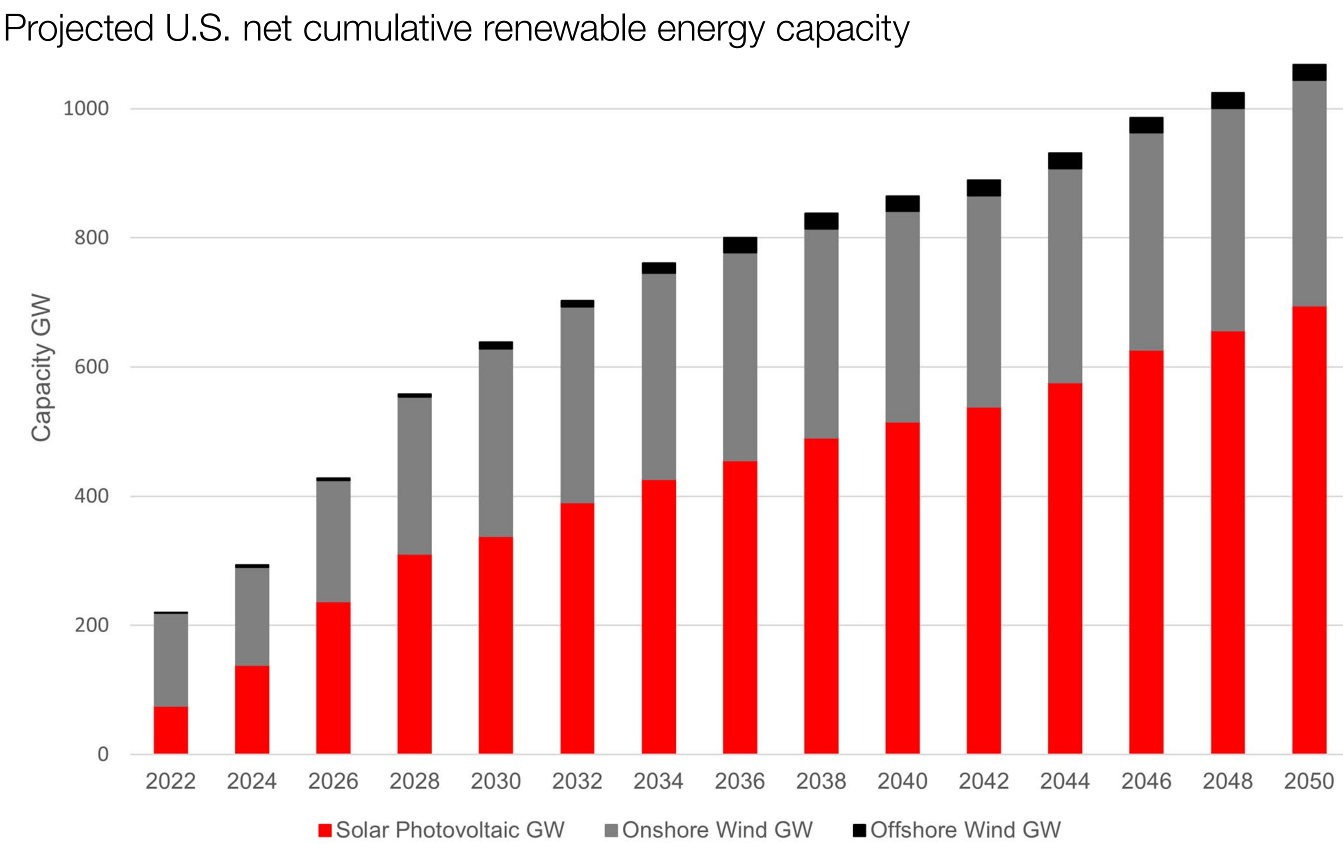
The overall mix of renewable sources has also been shifting over the last decade or so, with wind and solar exceeding hydropower, historically the largest source of renewable energy in the US. Initially, wind generation played the dominant role in this shift, surpassing annual hydropower generation in 2019. More recently, however, solar has begun to overtake wind.

The past decade saw dramatic growth in solar capacity installation with a year-over-year growth rate of almost 30%.[5] Wind power will continue to grow as well but is expected to slow toward the turn of the decade. There is about 140 GW of wind capacity installed in the US currently, which is projected to reach 350 GW by the middle of this century. [6,7] While offshore wind today is almost negligible in the US, it is projected to reach around 24 GW during this timeframe.[8] Hydroelectric capacity in the United States, in contrast, is expected to continue to hold steady at about 80 GW.[9]

It is clear that solar will play the dominant role in the US renewable power ecosystem, with solar installations growing to about 700 GW by 2050, growing almost 7X of present levels.[10] The reasons behind solar's ascendancy are manifold - besides being sustainable, it is a great job creator, easy to site, and most importantly, relatively low in cost.

Key factors driving the solar boom
The Levelized Cost of Energy (LCOE) for solar has decreased 83% since 2009, from about $360/MWh to about $60/MWh.[11] Even at this point, without anticipating further declines in solar's LCOE, it has reached a cost-competitive price point with coal, oil, and natural gas. Some analyses, like one reported by Lazard in April 2023, put the LCOE of unsubsidized utility scale solar as cheaper than all fossil fuels.[11] This is a major shift in the world of energy. No longer is adoption of renewable energy driven purely by environmental factors, it is now the economically sound choice.

The speed of deployment is of course also a factor helping to drive the solar industry's expansion. Solar is highly versatile from a siting perspective, suitable for deployment on rooftops, brownfields, etc. Also, in many situations there may be less 'not



01 Projected U.S. net cumulative renewable energy capacity (solar, onshore wind, offshore wind) Source: EIA

in my backyard' (aka NIMBY) concerns for solar compared to wind and other power generation plants. The supply chain for solar is well-developed and mature, as compared to hydrogen, and from a logistical perspective much easier to deploy than offshore wind. In addition, more than 40% of the US population lives within coastal counties, which cover a mere 10% of the nation's landmass.[12] This means there is substantial undeveloped land available for development in relatively sparsely populated areas.

Big backing

Government Support Driving Future Investment Government incentives have played an important role in the commercial development of the solar industry, driven by carbon reduction strategies. The US government's target of decarbonizing the entire US electrical supply by 2035 will naturally require a dramatic increase in carbon-free electricity production from all sources.[13] Both state and local incentives for both businesses and homeowners have encouraged development of solar, steadily improving its relative cost-competitiveness.

The increasing demand for energy and the obvious benefits of renewables have prompted many US states to develop their own renewable energy targets. While these targets vary quite widely, in sum they will demand that very large volumes of renewable energy be delivered to meet these goals. Solar continues to be one of the most promising options to achieve this.

Major allocations in both the Bipartisan Infrastructure Law, also known as the Infrastructure Investment and Jobs Act (IIJA), and the Inflation Reduction Act (IRA) promise to cement the role of solar and other renewable energy sources as key elements of the overall energy supply. The IRA tax credits in the form of ITCs or PTCs will phase out the latter by 2032, or when the electricity sector emissions are 25% of 2022 levels.[14] Wood Mackenzie in their latest report estimates that US electricity sector emissions will not reach the 25% level before 2050.[15] Hence, the Solar sector will likely continue to benefit from ITC / PTC support till at least 2050, providing all stakeholders with long-term certainty, further accelerating growth.

Additionally, the IRA has attracted more than $115 billion in clean energy manufacturing investments, including in solar generation.[16] Corporations have announced increases in US-based manufacturing of solar components and systems totaling billions of dollars in investment thus creating hundreds of well-paid green jobs.

Scaling up: Considerations for utility-scale solar

While size is a critical factor, defining a system as 'utility-scale' involves additional considerations. These systems not only 'collect' solar PV energy they also manage and regulate the flow of that energy and support its integration into existing transmission and distribution grids for delivery to residential and business customers, sometimes substantial distances away.

The figure below is a simplified diagram of a solar farm connected to the grid. DC power is fed from the modules to the combiner box, where it heads to the inverters for conversion to AC power. These are then fed to the setup transformer, where the AC voltage is adjusted to suit the grid. The power first passes through a meter and then onto the grid.

Depending on the size of a given solar farm, the power transmission infrastructure required can be quite substantial. Grid infrastructure elements such as inverters, transformers, and breakers, which are critical components of the system, are sophisticated and expensive. As a result, they need to be carefully planned for at the outset of any project. For example, depending on the location and available real estate, the size of substation components can be an important consideration. Utilizing technology like gas-insulated switchgear can allow for a reduced footprint while maintaining the efficiency of larger, less space-efficient alternatives. Equipment such as the step-up transformer, circuit breakers, communication, protection, and control equipment will be typically combined into a substation.

A typical step-up substation may include the following components:

- **Primary transformer:** Steps up voltage to the desired grid voltage.
- **Circuit breakers:** A key protection device that opens when relays detect faults.
- **Compensation and power quality devices:** Compensates for voltage fluctuations and regulates power.
- **Surge Arrestor:** Protects equipment from transient overvoltage, for example lightning or switching events.
- **Protection and Control systems:** SCADA and power plant controller (PPC) to ensure both compliance with ISO requirements and optimal plant operation.

Hitachi Energy offers solutions to address various needs of such solar plants, including power transformers, substations, power conversion system (PCS) units, circuit breakers, surge arrestors, protection and control, and high voltage switchgear.

Managing expectations: Trends and challenges of utility scale solar

While there is considerable momentum behind the development of the solar industry, addressing some significant challenges could encourage more rapid progress. Utility-scale solar is a complex business with many different stakeholders. A coordinated, collaborative approach to addressing key challenges will help the overall growth and acceleration of the sector.

Transmission and distribution needs
One of the most significant issues for developers is integrating solar projects into the existing grid. This requires approval from local authorities, cooperation with utility companies, and compliance with a variety of local and regional regulatory and technical requirements. In addition, since the existing grid was not designed with solar power generation in mind, in many cases high-capacity transmission links are not currently available to serve areas that are most suitable for solar development. Even those projects that align well with existing grid infrastructure will need to join the queue for new grid connections years before the project can come online.

Continued large-scale implementation of solar, particularly to meet corporate and government goals, requires upgrading aging grid infrastructure in the US. These upgrades need to expand capacity to transfer power from areas with favorable conditions for renewable energy development to major load centers, and bridge regional 'seams' in the process. A high-quality transmission network can also help with the intermittency of renewable energy by enabling movement of renewable power over large distances, helping regions balance each other's supply.

Recent Department of Energy (DOE) funded studies such as NREL's Interconnection SEAMS study and the DOE's National Transmission NEEDS study highlight the importance of transmission investment, particularly in high voltage direct current (HVDC) technology to make the grid resilient and flexible, enabling large-scale renewable integration.[17,18] Further, the recently approved FERC order 1920 is expected to be a key enabler of long-distance inter-state transmission line build-out.[19] Hitachi Energy is a pioneer in HVDC with more than 150 GW of installed base around the globe. Some of the notable new HVDC projects announced in the US where Hitachi Energy's HVDC Light® system was selected include Champlain Hudson Power Express and the SunZia Transmission project.[20, 21]

Connecting the dots: Supply chain opportunities
Supply chains are another area where there are significant opportunities for improvement. Thanks to decarbonization efforts being pursued by governments and private entities globally, the demand for renewables, especially solar, has skyrocketed. While this represents much-needed positive acceleration toward the achievement of our climate goals, the global supply chain for the electrification industry is not yet equipped to handle this unprecedented demand. For utility-scale project developers, it is now essential to secure the needed equipment, expertise and eventually the workforce to support projects that may be 3-10+ years from delivery. This is a drastic shift for an industry that typically operates using a project-by-project planning horizon.

Presently, developers design, build, and operate each project largely independent of each other. For critical long-lead components such as transformers, this creates unique requirements for each project, requiring significant customizations and resulting in increased lead times and costs. Additionally, such a project-by-project approach can also hinder standardization of asset maintenance strategies, thereby increasing operation and maintenance risks and costs.

Hitachi Energy, through its Power Consulting team, has worked closely with a variety of developers across the globe to help them standardize design of their critical subsystems and components including HVDC equipment, transformers, breakers and switchgear, digital control and asset management systems, etc. Early engagement is essential in this context, as it will help facilitate co-creation of solutions that could be replicated over multiple projects. It also enables the 'de-risking' for procurement of long-lead-time items through vehicles such as capacity or frame agreements. A great example is a recent 2 GW HVDC multi-project agreement with TenneT, where Hitachi Energy will deliver six HVDC systems, each of 2 GW capacity in the coming years.[22]

One consideration somewhat unique to the US is the push to establish domestic content requirements for projects being developed in the country. While many key players in the renewable energy ecosystem, such as Hitachi Energy, have significant and expanding manufacturing capacity in North America, the supply chain for solar PV systems within the US is not currently sufficient to meet overall demand. Similar challenges face developers of the adjacent infrastructure needed to support the grid interconnections needed to enable the pipeline of solar PV projects under development.

Developing and scaling up resilient clean energy and technology supply chains will be essential to meeting the Biden Administration's goal of 100% clean electricity by 2035 and a zero-emissions economy by 2050. Global companies, such as Hitachi Energy, in addition to investing heavily in the US, will need to be able to leverage global footprints without being constrained by trade barriers/tariffs. It is not feasible to manufacture all components and systems locally. Such measures will likely create bottlenecks and make products less competitive. Policies that balance domestic and imported components and systems will be necessary to ensure the clean energy transition's success.

The challenge of future-proofing: Growing expectations for grid services

As solar PV assumes a more central role in the overall energy mix, the expectations are continually growing for solar power plants (particularly larger, utility-scale systems) to deliver critical grid services. A decade ago, most solar installations were relatively small, 10 MW or less, and were not considered a central grid component. In contrast, today's larger solar installations are often hundreds of MWs, even multiple GWs, and critical to the overall power supply. Grid codes, essentially 'electrical codes of conduct' for all generation sources, including renewables, were introduced in the early 2010s. Over the past decade, as solar farms have grown in size and importance, these grid codes have evolved to ensure that renewable resources bear their share of responsibility for the management and stability of the grid.

While these codes vary by country, the underlying principle is similar. When initially introduced, there were limited expectations placed on solar plants, primarily the need to disconnect safely from the grid in response to disturbances such as faults. Gradually, they were entrusted to contribute reactive power support. Increasingly, they are now required to provide more complex, essential grid services, such as frequency regulation and potentially even black start in the near future.

A typical utility-scale solar plant has a lifetime of 25+ years. New solar plants must be flexible enough to adhere to future grid codes that aren't even being discussed today. The key is not to over-design projects that are already capital-intensive; instead, the focus needs to be on incorporating key flexibility features in hardware and digital components. Hitachi Energy has a comprehensive portfolio of hardware and software solutions that provide these key flexibility features over the lifecycle of a project.

For example, power quality is often a major consideration for utility-scale solar projects. Several factors such as the size (in MVAR) of reactive compensation required, the speed of compensation, as well as harmonic spectrum are considered in the design of the appropriate power quality solutions. Hitachi Energy's portfolio of Power Quality Solutions includes fixed capacitor banks, filter-ready capacitor banks, harmonic filters as well as Static Compensators (STATCOMs).[23] Fixed capacitor banks are typically recommended when the reactive power requirement of a solar plant is relatively stable over time. On the other hand, if the reactive power requirement varies significantly, especially during fast transient scenarios like faults, a STATCOM may be a better solution. Additionally, newer solutions like Hitachi Energy's SVC Light® Enhanced STATCOM can also provide controllable inertial response in a matter of milliseconds, which may allow solar plants to execute more complex functionalities. This wide portfolio allows developers to consider not just the present requirements, but also future flexibility needs in selecting the appropriate power quality solution.

Optimizing total cost of ownership

In the US, most utility-scale solar projects are owned and operated by developers, and the business models for these projects have evolved significantly over time. Historically, much of the focus of early solar projects was on reducing capital expenditure (CAPEX). However, as the industry has matured, project owners are keen to optimize their returns on investment (ROI) by maximizing potential revenues and minimizing total cost of ownership (TCO).

In the planning phase, it is critical to have a reliable forecast of revenue throughout the project lifecycle. Hitachi Energy's Power Reference Case (formerly Ventyx Price Curves) offers granular electricity market forecasting over the next 25 years, including hourly, monthly, and annual electricity prices under various scenarios.[24] This helps a project build a reliable revenue forecast using locational marginal prices (LMP) predictions, curtailment analysis, and other variables. In addition, Hitachi Energy's Power Consulting team, which has deep expertise in energy markets, can also advise on potential revenue streams through participation in ancillary energy markets when applicable. The developed revenue maximization strategy can be implemented using technologies like Energy Trading and Risk Management (ETRM), SettlementTracker, and RECTracker.[25]

To minimize TCO, it is not only important to have a good handle on CAPEX, but also critical to develop a comprehensive asset management strategy. Hitachi Energy's Lumada Asset Performance Management (APM) empowers developers to take a strategic and proactive approach to a reliability-centered asset maintenance strategy. The solution delivers prescriptive, data-based insights and recommendations for proactive maintenance and planning utilizing a broad range of physics, statistical, artificial intelligence, and hybrid-based modeling methodologies, so organizations can maximize their time and budgets.

A photovoltaic finish? The solar boom is central to a brighter future.

To answer our question at the beginning, the renewable energy landscape of the future will be much more expansive than what we see today. It will also be foundational to the energy future. Behind every interaction we have – from transportation to communication to consumption, it will all be powered by electricity. Based on the industry's current trajectory, solar will play a critical, if not the central role in enabling people to live sustainable, fulfilling lives, build communities, and solve the big challenges of our time. The world of 2050 will hopefully be a brighter place – for our society to flourish, we need to bring all of our skills and expertise to bear to enable solar to meet its potential.

Renewable energy development has been on a steady, upward trajectory over the past decade, and forecasts suggest continued growth in the coming years. Opportunities abound for investors, developers, electrical contractors, original equipment manufacturers (OEMs), and governments to deliver economic growth while also supporting sound environmental policies and sustainability targets. Solar PV is perhaps the most promising segment of the renewable energy market, based on technical maturity, flexibility of siting and deployment, and strong economics.

It is also promising in terms of the availability of capital. Solar projects offer prime opportunities for financial institutions to utilize energy performance contracting (EPC) as the LCOE of renewable energy continues to drop. Large areas of the country have exceptionally good solar resources and plummeting costs in recent years have given solar the infrastructure needed to contribute to local employment for installers and engineers. The reality is that solar represents a particularly attractive, low-risk option in the US.

Encouraging solar development is a sound public policy. The solar industry is a great job-creator, with investments in solar photovoltaic energy generating 1.5 times as many jobs as investing the same amount in fossil fuels.[26] Most of the money spent on solar farms is spent internally within the country and jobs are created in two areas – high value technology roles and manufacturing, installation, and support positions. Additionally, many of these jobs are in remote areas that often lack appealing employment opportunities.

Momentum behind solar development continues to build. To ensure that the industry continues to thrive and deliver on its potential, the US needs to foster a network of partnerships across the value chain. Governments, both national and local, as well as grid planners, operators, technology vendors and suppliers, investors, we all have critical roles to play in removing obstacles and maintaining progress.

The solar power system – not the one in the sky, but the one here on the ground, will enable us to build a sustainable energy future for all.

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Hitachi Energy USA Inc.
901 Main Campus Drive
Raleigh, NC 27606, USA

Contact us:
US & Canada: +1 800-290-5290
Mexico: +52 800-681-6535
hitachienergy.com/contact-us

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