A Decade In The Making – Siemens Energy HL-class Now Delivers Power To The Grid

This paper presents the evolutionary Siemens Energy HL-class gas turbines and power plants. The HL-class combines best-in-class technology innovations with the rich heritage of the proven SGT-8000H series design resulting in a technology carrier to the next levels of performance. The SGT-8000H series has set the standard in terms of design robustness and reliable operation and has become the benchmark for clean fossil power generation all over the world. Building on a decade of further technology evolution and applying latest engineering tools and methods, the SGT-9000HL was delivered to its first customers and is now delivering power to the grid.

With the HL-class, Siemens Energy continues its leadership in large air-cooled gas turbines by pushing efficiencies beyond 64% gross today and even higher in the future. The HL-class is designed for the highest operational reliability and flexibility to fulfill the requirements of base load units while also being a perfect fit for peaker applications. This makes the HL-class a versatile solution for operators who anticipate the need for energy systems with a rapidly increasing share of fluctuating production by renewables. To make sure that HL-class customers are ready for the future, the HL-class comes with digital offerings, best-in-class service and trendsetting hydrogen capabilities.
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<th>Description</th>
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<tbody>
<tr>
<td>ACE</td>
<td>Advanced Combustion system for high Efficiency</td>
</tr>
<tr>
<td>AIP</td>
<td>Auxiliary Integrated Package</td>
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<tr>
<td>AM</td>
<td>Additive Manufacturing</td>
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<tr>
<td>CC</td>
<td>Combined Cycle</td>
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<tr>
<td>CEC</td>
<td>Clean Energy Center</td>
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<tr>
<td>CPO</td>
<td>Plant Continuous Performance Optimizer</td>
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<tr>
<td>DOE</td>
<td>(US) Department of Energy</td>
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<tr>
<td>EBH</td>
<td>Equivalent Base Hours</td>
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<td>ES</td>
<td>Equivalent Starts</td>
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<td>GT</td>
<td>Gas Turbine</td>
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<td>GT AT</td>
<td>Gas Turbine AutoTuner</td>
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<tr>
<td>GW</td>
<td>Gigawatts</td>
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<tr>
<td>HCO</td>
<td>Hydraulic Clearance Optimization (system)</td>
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<tr>
<td>HRSG</td>
<td>Heat Recovery Steam Generator</td>
</tr>
<tr>
<td>I&amp;C</td>
<td>Instrumentation &amp; Control</td>
</tr>
<tr>
<td>IoT</td>
<td>Internet of Things</td>
</tr>
<tr>
<td>LCOE</td>
<td>Levelized Cost of Electricity</td>
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<tr>
<td>LEG</td>
<td>London Engineering Group</td>
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<tr>
<td>MW</td>
<td>Megawatts</td>
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<tr>
<td>NOx</td>
<td>Nitrogen Oxides</td>
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<tr>
<td>O&amp;M</td>
<td>Operation &amp; Maintenance</td>
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<tr>
<td>SGT</td>
<td>Siemens Gas Turbine</td>
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<tr>
<td>SCC</td>
<td>Siemens Combined Cycle</td>
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<tr>
<td>TBC</td>
<td>Thermal Barrier Coating</td>
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1. Siemens Energy Large Gas Turbine Development

At Siemens Energy, we create our GT product line based on our own holistic design philosophy. With strict attention to customer goals and requirements, we take technology to new levels to attain the best full life value that is fully optimized in safety, performance and environmental requirements. This holistic method starts with the fleet experience of over 7,000 installed heavy duty, industrial and aero-derivative gas turbines, proven in the diverse environments and economies of 60+ countries. Critical data from many functions like engineering, manufacturing, repair, sales, and marketing play an important part of the foundation of our evolutionary design. This coherent and confident information is compiled and shared as technology download. Siemens Energy has made use of its global diversity to establish a robust design Philosophy that balances strong engineering discipline with open creativity to make innovative changes with incremental confidence. We step with confidence from proven design and we step with confidence from rigorous testing of new innovations. New technology is tested at each stage of development, from component rig testing, to full scale engine testing and finally site validation testing.

*Figure 1 Siemens Energy Evolutionary Design Cycle*
2. Siemens Energy H-class Heritage and HL-class Evolution

The Siemens Energy SGT-8000H series was successfully introduced into the market and is well received by customers all over the world. It is the market leader in the air-cooled H-class with 94 engines sold and more than 1,500,000 fired hours across four continents. It was designed to not only achieve high efficiencies but also to meet flexible operating requirements, while maintaining the durability and reliability of the previous design heritage. Since the first commercial installation, it has reached unprecedented levels of reliability and efficiency to the satisfaction of its customers.

Siemens Energy has introduced and operated the new HL-class as the technology carrier to the next level of performance. It is based on the reliable engine architecture of the SGT-8000H series proven with a decade of successful operation. With the HL-class, Siemens Energy combines experience with cutting-edge technologies to build the future.

Figure 2 Siemens Energy large gas turbine portfolio evolution

In simple-cycle operation the air-cooled SGT-9000HL gas turbine has the capacity of 405 MW for the 60Hz and 593 MW for the 50Hz version. The HL-class exceeds 64 percent combined cycle gross efficiency and even higher performance in the future.
3. Reliable Design DNA

The HL-class is founded upon H- and F-class engine architecture elements that have proven to support both reliable and flexible operation. Some of these proven elements are:

- Single tie-bolt rotor that allows for high load gradients by creating internal cooling air passages and enables rotor de-stack at site, if necessary
- Hirth serrations that prevent rotor imbalance by allowing for self-centering of the rotor discs
- Conventional steel rotor disc materials with high toughness capability allowing for highest reliability, fast starts and flexible transient operation
- Can annular combustion system with identical burner count for H- and HL-class engines building on the proven rig to engine experience
- Air cooled four stage turbine which is a proven and reliable design
- The Hydraulic Clearance Optimization (HCO) which increases turbine performance during operation by actively managing clearances during start and transient operation and enables unrestricted hot re-starts
4. Cutting-edge Technologies

Siemens Energy gas turbines have evolved for over 60 years and provide a robust and reliable source of energy. The evolution of the gas turbine can be categorized into improvements in aerodynamics, cooling designs, coatings systems, combustion systems, and new manufacturing technologies. Through dedicated technology programs, Siemens Energy has placed continuous focus on these technology disciplines using a practical approach of design, component testing, prototype testing, and full engine validation testing. Through this rigorous process, performance of the Siemens Energy portfolio continues to improve while maintaining a world class gas turbine reliability. The technology development process is executed prior and in parallel to the product development process since they mature at different rates. Only once a technology is mature, will it be incorporated into a standard product. This approach allows Siemens Energy to gain valuable practical experience well in advance of product introductions and share the matured benefits of the technology with customers.

Taking full advantage of the Siemens Energy technology development process, the SGT-9000HL development team utilizes state of the art virtual design modelling tools and balances the result with detailed and complete empirical data. This establishes a cycle of continuous improvement in the engineering tools as well as the final product. Modelling allows rapid iteration, while empirical measurement assures a check, balance, and refinement of the model. The team applies multi-disciplinary optimizations including state-of-the-art flow simulations, aerodynamics, and structural mechanics in combination with component testing, prototype testing, and full engine validation testing.

For the compressor module, the SGT-9000HL engineers developed advanced compressor 3D blading including end-wall contouring and advanced blade tip designs for improved aerodynamic characteristics, as well as increased performance during part-load operation.

In the mid-frame module, the HL-class Advanced Combustion system for high Efficiency (ACE), provides both low emissions and high efficiency as a result of the innovative jet-stabilized combustors with an increased number of premix fuel injectors. Higher efficiency and lower NOx emissions result from improved fuel/air premixing, reduced residence time, and a design requiring less cooling air, even at higher firing temperatures.

The turbine module integrates various key technologies such as super-efficient internal cooling features, advanced modular thermal barrier coatings (TBC), and a free-standing turbine blade 4. The cooling features are based on Siemens Energy’s proprietary casting core geometries.
facilitating improvements in cooling air effectivity and thus reducing cooling air and associated losses. The improvements in cooling effectiveness allow for the utilization of proven advanced materials such as directionally solidified blade castings. The ideal thermal barrier coating would have several contrary properties like: resistance to cracking by conforming to stain, high porosity and low thermal conductivity to minimize heat transfer, excellent bond strength as a prime reliant barrier and high oxygen affinity to protect the base metal from oxidation. To this end, Siemens has heavily invested in the development of an advanced modular TBC system over the last two decades, allowing for various coating elements to be combined to meet a variety of diverse thermal, mechanical and operational demands. Enhanced strain tolerance of the coating is a key achievement, ensuring coating robustness even in the most extreme conditions. A free standing, internally cooled turbine blade 4 has been optimized to allow for maximum gas turbine output and provides best-in-class efficiency.

Additive Manufacturing (AM) is a technology, that Siemens Energy has successfully developed and implemented in industrial gas turbine engines. Based on more than 10 years of progressive testing including lab scale, component and engine level, Siemens has already implemented and validated various hot gas components with more than 160,000 accumulated engine operation hours for standard production parts. The HL-class builds on this legacy and incorporates AM technology to take full advantage of designs that are no longer inhibited by limitations of conventional manufacturing processes. AM significantly improves design options for fuel delivery, cooling, and instrumentation systems that further drive performance and safety.

Figure 5 HL-class key technologies
5. Testing and Validation

As Lord Kelvin once said, “to measure is to know”. Measurement has been at the core of most scientific proof and as important as it has been, measurement is even more important today. With the advent of modern modeling tools, virtual simulation and autonomous operations, measurement is critically required to assure these new tools are properly and thoroughly representing the engines and plants in respect to design, manufacturing, operation and life prediction. The iterations of model-build-measure-improve model create a technology propelling cycle of continuous improvement for the products and analytical design tools of Siemens Energy engineering.

Testing and validation are an integral part of Siemens Energy gas turbine development as it ensures high reliability and availability for products and technologies. Siemens Energy testing and validation methodology has proven to be successful with the seamless introduction of the SGT-8000H series and continues to be a cornerstone of Siemens Energy product design philosophy. Upgrade components, gas turbines and technical solutions pass through a series of tests designed to meet the market needs for lowest technical and commercial risks. The key technologies developed for the HL-class have been thoroughly tested and validated including: component testing at the Clean Energy Center (CEC) in Ludwigsfelde close to Berlin, prototype testing at Siemens Energy Berlin Test Facility and validation testing under real site conditions in the Siemens Energy operating fleet.

The last step in Siemens Energy testing and validation process is a thorough full engine validation test. The SGT5-8000H was validation tested in Irsching from 2008 to 2011 in alliance with E.ON SE. Similarly, the HL-class is being validation tested at Duke Energy’s Lincoln County site starting with first fire on April 6th, 2020. The Duke Energy validation test alliance is extremely beneficial as it allows the engineering team to thoroughly study all critical components and operational response for more than 8000 hours using more than 6000 simultaneously monitored sensors. Multiple operating modes are being tested including natural gas, fuel oil, wet compression and hot ambient simulation (enabled by an air pre-heater installed at the facility). Additionally, the 50Hz version of the HL-class, the SGT5-9000HL, will be validation tested at the SSE Keadby II plant in UK starting in 2021. At both Lincoln County and Keadby II, Siemens Energy tests the engines with on-grid operation to validate the durability of the components in long-term endurance runs.

Allianz, a global insurance company, appreciates Siemens Energy’s testing and validation approach and the evolutionary design philosophy. Based on that, an insurance panel led by Allianz
guarantees a LEG2 equivalent insurance for all upcoming SGT-9000HL projects. To date, 6 of the sold SGT-9000HL units have a market common insurance coverage.

**Figure 6 Siemens Energy 3-step testing and validation concept as applied for the HL-Class**

### 6. Global Market Acceptance

The global trends population growth, urbanization, decarbonization, fuel price and renewable energy production have caused dramatic changes in the energy markets. The HL-class is one of Siemens Energy’s answers to the energy transition and was designed to perform in current and future anticipated environments.

As mentioned above, Duke Energy – one of the largest utilities in the United States, with 58 GW of installed base has chosen the HL-class as the means to provide flexible peaking power to complement its growing renewable generation assets. The first SGT6-9000HL engine was built and assembled in Charlotte, North Carolina, only few miles away from the Lincoln County power plant. On October 22nd, 2019, Ex-Works was achieved, and the GT was delivered to site marking an important milestone in the HL-class development. Less than 6 months later, on April 6th, 2020, the GT was ignited for the first time. Since first fire, the Siemens Energy O&M team is validating the engine operation profiles as predicted by the design team.

> “When investing in a new generating asset, we consider performance, efficiency and costs over the entire 30-year-plus life cycle of the unit.”

Kevin Murray, Duke Energy’s Vice-President of Project Management and Construction
In the 50 Hz regions, Scottish & Southern Energy (SSE), the United Kingdom’s broadest base energy company has selected the HL-class to provide the highest efficiency supply in the UK energy grid contributing to reducing the carbon footprint of its base electric generation. SSE’s SGT5-9000HL was manufactured and assembled in the Siemens Energy Berlin factory and left the site on May 15th, 2020. The engine was shipped across the English Channel, brought to the Keadby site and installed. SSE and Siemens Energy are looking forward to first fire in 2021.

“SSE is very pleased to have this unique opportunity now to be partner with Siemens […]. The highly efficient technology, not previously seen in the UK, will provide firm, reliable power […] at half the carbon emissions of the coal generation it is replacing.”

Martin Pibworth, SSE wholesale director
Cooperative Energy’s Morrow Repowering project will achieve significant carbon reduction while demonstrating the SGT-9000HL’s potential in a brownfield project application. By replacing the original coal fired plant, both CO₂ and NOₓ will be reduced by approximately 60% and 80% respectively. The site’s existing steam turbine will be reused as part of a highly cost-efficient solution.

“The Cooperative Energy consultants and staff went through a rigorous evaluation of the various combustion turbine technologies available and selected the Siemens HL-class gas turbine as the best overall technology for the Morrow Repower Project. ”

Nathan Brown, Cooperative Energy’s senior vice president and chief operating officer

The HL-class is generating high attention around the world, in Europe, the Americas and Asia. A Korean major utility continues to rely on proven Siemens Energy combined cycle technology and has signed contracts for a power island scope totaling four SGT6-9000HL. Hence, the Korean track record of reliable power generation provided by Siemens Energy will continue.

North and South America, Europe and Asia have already chosen the SGT-9000HL as its technology carrier for electrification and industrialization of the global power generation market. The HL-class is globally accepted as the leading power generation equipment to provide unique value for its customers during the energy transition.
7. Constructability

In June 2015, Siemens was awarded an order for the expansion of the Egyptian power supply. 27.5 months after signing the contract, Siemens Energy established a new worldwide benchmark for the execution of fast-track power projects. The mega project in Egypt promised and delivered a goal of providing 14.4 GW of new capacity to the grid. The last of 24 SGT5-8000H gas turbines was successfully synchronized on the 24th of June 2018. Since then, the three power stations are the largest gas-fired, combined cycle power plants ever built and operated in the world. The dimensions of the megaproject are enormous: More than 20,000 workers were engaged at the construction sites during implementation, accumulating 3,695,600 man-hours per month. Over 1.6 million tons of material were handled.

Building on its outstanding project execution experience, Siemens Energy offers the construction of its combined cycle power plants with prefabricated building blocks which accelerate schedules significantly while also improving safety and quality. The modular concept begins with the GT package: The auxiliary integrated package (AIP) consists of several prefabricated steel racks that have piping, valves, and junction boxes already pre-installed when they arrive at site. This helps to reduce on-site construction labor by more than 8000 hours. It also helps to streamline maintenance work with savings in cost, time, and manpower.
But modularity doesn’t stop there. Siemens Energy Solution Building Blocks can be applied for pipe racks and system modules as part of the Power Island and Power Core scope. While the traditional stick-built construction of a pipe rack may take up to 15 weeks, the installation of the prefabricated version can be completed on site in only five days. Overall, the erection and commissioning time of combined cycle power plants can be reduced by up to 8 weeks with approximately 80,000 man-hours of savings at the construction site.

The Siemens Energy Solution Building Block concept was successfully implemented in multiple instances: Knapsack II in Germany, La Caridad in Mexico, Lordstown in Ohio (USA), GNA in Brazil. The first SCC5-9000HL 1x1 plant Keadby II in UK is built using the full range of Siemens Energy Solution Building Blocks. As an example, Figure 13 shows the steam turbine hall of the Keadby II plant. The 3D model shows a slightly different configuration compared to the project site picture.
8. Flexibility

Highly efficient and flexible gas-fired power plants are the perfect fit to energy systems with a rapidly increasing share of fluctuating renewables. Therefore, highest flexibility was a key design target for the development of the HL-class. The SGT-9000HL allows GT fast starts in 10 minutes for 60Hz and 12 minutes for 50Hz, combined cycle hot starts in less than 30 minutes and the GT can ramp-up with up to 85 MW per minute.

**Figure 14 SGT-9000HL fast start capability**

The gas turbine is the main driver for flexibility, but it has to work in concert with the whole plant including I&C system, auxiliaries, heat recovery steam generator (HRSG), and steam turbine in order to achieve highest plant flexibility. As a result, Siemens Energy plant solutions has developed corresponding plant operation offerings. These offerings combine a set of engineering philosophies into a single integrated plant concept resulting in increased number of starts and faster start-up times.

For HL-class flexibility concept an integrated design approach was chosen, ensuring a perfect fit between gas turbine and plant-level flexibility features in Siemens Energy combined cycle offerings, including power island, power core and turnkey power plant. For these offerings, technology innovations like Co-Start™, Quick-Stop™, Clean-Ramp™ and DASH™ systems are available. This makes the HL-class the flexibility leader of the combined cycle power generation market.
9. Service

The global service team embodies the combined knowledge and experience of the Siemens Energy global fleet. Currently, the service team has experience with more than 1,300 large gas turbines. The highly professional field service and service engineering teams are dispersed globally across 20 offices in 14 countries. Along with the multiple service repair shops and warehouses worldwide, the team can provide a timely maintenance response anywhere on earth.

*Figure 15 Siemens Energy field service – combining experience with latest technology*

The HL-class is designed to maximize serviceability, leading to highly competitive maintenance intervals for increased engine availability. The maintenance concept is suitable for various operating regimes including both hours-driven and starts-driven operation. The base concept is a 33000 EBH concept (alternate 1250 ES) without part-load factors resulting in best in class availability.

Like the SGT-8000H series engines, the SGT-9000HL also has a proven single tie-bolt rotor design which allows for easy on-site de-stack. The turbine stage 1 vanes and blades and stage 4 blades can be removed and replaced without a cover-lift. All compressor and turbine blades are removable without a rotor lift. The design of the turbine casing enables roll-in/roll-out of stationary parts with the rotor in place. Innovative field service concepts are applied to maintain the engine for a multitude of outage types with optimized outage duration, enhanced flexibility, precision and safety.

*Figure 16 Serviceability of Siemens Energy gas turbine components*
10. Digitalization

Siemens Energy digital offerings are designed to maintain profitable life-cycle operation, increase availability, optimize performance and flexibility, while complying with asset cyber security. Over the last 20 years, Siemens Energy has collected operating data and monitoring experience of over 38 million operating hours. Building on this experience, the HL-class offers cloud-based digital applications supported by Omnivise Digital Services with Industry IoT operating system connectivity, visualization, monitoring and optimization. The digital applications offer advanced analytics and intuitive insights through customizable apps. Connecting turbines and plants to operators and management via the Siemens Energy digital world enables our customers to uncover transformational insights in all functions across their business.

Utilizing edge outputs, operating parameters, plant condition performance monitoring and data analytics, Siemens Energy provides intuitive insights in engine operation, plant optimization and decision support for operation and maintenance. Advanced operation simulation for training, risk mitigation and integrated digital asset management are available to help operators make confident decisions and for quick access to relevant information. Edge devices provide live, high fidelity data for control closer to the equipment. They also prepare the plant for next generation autonomous operation tools.

Customized digital value stream packages ranging from GT AutoTuner to Plant Continuous Performance Optimizer (CPO) can be provided for the HL-class to meet customer specific needs and improve performance, reduce degradation and maximize availability over the plant lifecycle. The GT AutoTuner (GT AT) is an integrated physics based thermal model and machine learning data-driven model working together to continuously adapt to expected changing conditions such as machine wear and/or fuel composition variations. The GT AT allows continuous emissions and combustion dynamics tuning of the engine, with the help of self-learning algorithms. It is designed to autonomously optimize plant operation as directed by the operator to determine and set controls for best performance and emissions and is especially valuable for peak and part load operations.
The Plant Continuous Performance Optimizer is part of the Omnivise suite of operational condition monitors. This tool is based on over 20 years of OEM expert knowledge from Siemens Energy's global fleet. Combined results from a physical modeling tool and advanced analytics help customers to optimize their asset management.

11. Hydrogen readiness

Today, gas turbines play a vital role in addressing the threat of global warming. Gas turbines are in the category of the cleanest fossil-fuel based power generation solutions and are ideally suited to manage the intermittency of increasing renewable loads by providing reliable and on-demand power. Gas turbines will remain an even more important element in power generation as electrification trends toward full decarbonization and the hydrogen economy starts to unfold. By burning hydrogen as a fuel, either through co-firing or complete displacement of natural gas, gas turbines can provide low-carbon or even carbon-free power solutions.

Siemens Energy has the technical expertise and is determined to drive the decarbonization process of the energy sector. In 2019, as part of its commitment toward environmental sustainability, Siemens Energy signed a European industry agreement that promises that its gas turbine portfolio can be operated with 20% hydrogen by volume mixed with natural gas by 2020 and 100 percent hydrogen from 2030 onwards. Only one year after signing the agreement, Siemens Energy has made a 30% hydrogen package available.

Siemens Energy gas turbine fleet experience with high hydrogen content fuels is extensive, with more than 55 units around the world amassing 2.5 million operating hours since the 1960s. From 2005 to 2015, Siemens Energy participated in an US DOE program focused on H₂ combustion technology for large gas turbines, setting the basis for the hydrogen capabilities of the HL-class dry low emission combustion system. Today, the HL-class can be offered with up to 30% hydrogen. Combustion, auxiliary and plant engineers are working on extending the capability to 100% by 2030. This gives a high investment security to HL-class customers by making sure that their assets will continue to run on high capacity factors even under future market conditions and environmental requirements. The HL-class hydrogen roadmap is shown in Figure 18.
12. Conclusion

Siemens Energy delivers on promises. Even highly complex projects are delivered on time and with highest quality. With its latest development in the gas turbine and power plant portfolio Siemens Energy demonstrates once again its leadership in innovation and technology.

The HL-class shares the same DNA with the SGT-8000H series that has globally collected more than 1,500,000 fired hours of fleet experience. The HL-class is well received on all global markets and has been ordered by customers in North- and South America, Europe and Asia. With the LEG2 insurability backing from Allianz, the HL-class is on its way to become the market leader in reliability and best-in-class performance.

The Siemens Energy HL-class offers its customers improved performance and availability, higher operational flexibility, improved constructability, lower maintenance costs and hence lower levelized cost of electricity. With hydrogen technologies and digitalization offerings, Siemens Energy ensures the HL-class is future ready so that customers can rely on a high investment security by assuring that their assets will continue to run on high capacity factors even under future market conditions and environmental requirements. The HL-class delivers what Siemens Energy is best known for: reliable, high performing, cutting-edge technologies.
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For further information on the HL-class, please see Link

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