PENIEL
IMPACT

Lumin Plus ™

WHITE PAPER

RESOURCE PLANNING

"Energy too cheap to meter," Lewis L. Strauss, the chairman of AEC

NETZERO

In the journey towards achieving net-zero emissions, Long Duration Energy Storage [LDES] assumes a pivotal and indispensable role. It serves as a crucial component contributing to the successful transition and sustainability of the energy landscape.

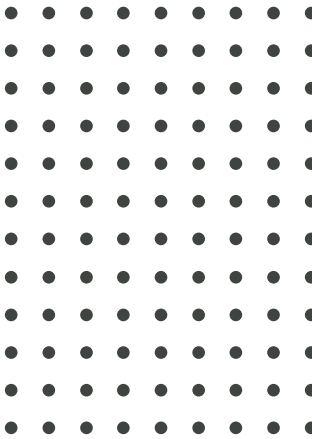
JUST TRANSITION

The global shift towards achieving net-zero emissions must be conducted with a commitment to fairness and justice, prioritizing the upliftment of overburdened and underserved communities. It is imperative that this transition not only addresses environmental concerns but also actively promotes social equity and inclusivity.

Introduction

Lumin Plus™ is our capacity expansion and dispatch model for the electric power sector that relies on system-wide least cost optimization to estimate the type and location of future generation and transmission capacity for corporates.

The Lumin Plus™ model was developed to assess the long-term market penetration of Renewable Energy [RE], in the electric power sector. Over time, we have enhanced the Lumin Plus™ model to conduct diverse analyses related to renewable energy, covering aspects such as, the influence of policies on renewable energy deployment, the role of distributed renewable energy in power markets, the effects of high renewables penetration on manufacturing, the potential synergy of offshore wind plus storage, and the advantages of energy storage for wind power.



Presently, we are actively developing a module within Lumin Plus™ to analyze the role and potential of the concentrating solar power [CSP] market, exploring its interaction with policies at both country and global levels.

Lumin Plus™ stands out as a specialized tool for examining the intricate interactions and long-term deployment scenarios of renewable energy technologies in the power sector, benchmarked against other alternatives. It is primarily designed for scenarios aligned with NetZero 2050 objectives.

Positioned strategically, Lumin Plus™ is poised to become the primary analytical tool for comprehensive studies focusing on the Hydropower 2050 Vision, Nuclear 2050 Vision, Wind 2050 Vision, Solar 2050 Vision, Renewable 2050 etc, all firmed up with LDES. It will aid our clients in crafting annual scenario reports, offering insights into the electric sector outlook under a diverse range of potential renewable energy futures. Additionally, Lumin Plus™ is instrumental in examining the impacts of various existing and proposed renewable energy policies.

Lumin Plus™ also examines the role of natural gas, high renewable scenarios, and other important issues for the electric power sector.

Background & Capabilities

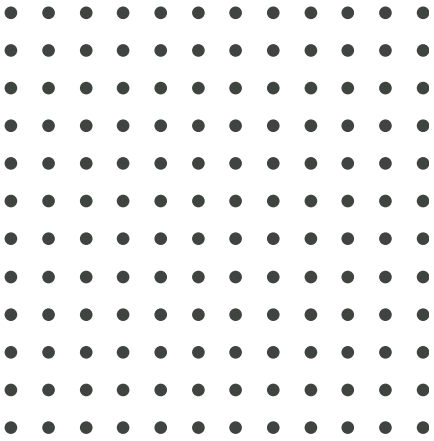
With Lumin Plus™, you have the capability to:

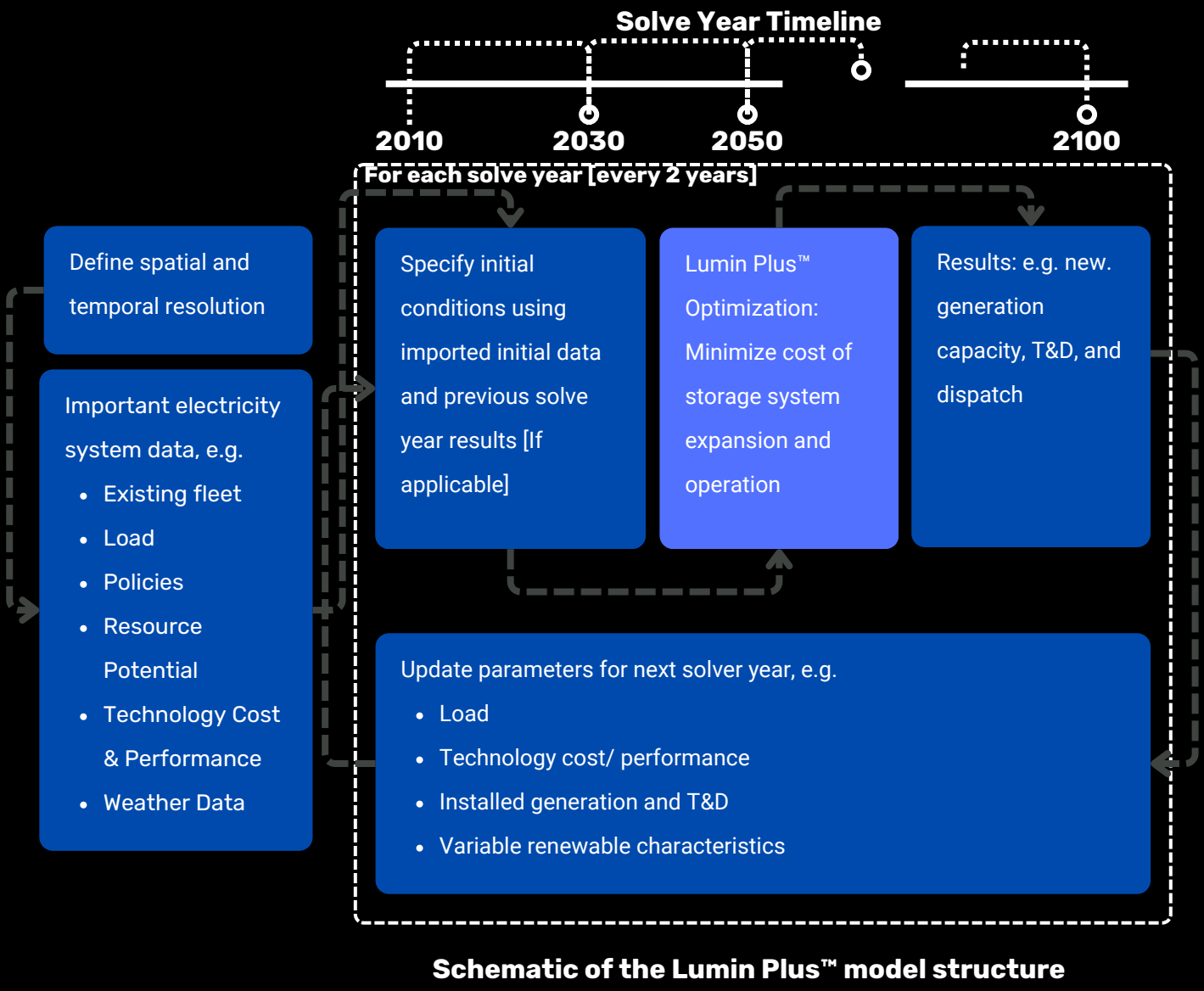
Examine routes for reaching carbon neutrality in the power sector by 2050 through a thorough analysis. Employ a range of planning tools, such as resource assessment, capacity expansion modeling, and production cost modeling.

Produce solar and wind profiles on an hourly basis, incorporating energy storage for reliability, and assess resource potential. Take into account spatial exclusions, including considerations for urban areas, bodies of water, protected lands, sloped terrain, and proximity to structures [setbacks].

Identify the most economically efficient pathway of capacity to fulfill decarbonization goals while also meeting crucial system requirements, such as.

- Balance the load by aligning supply with demand in each time slot.
- Plan for reserves to ensure adequate capacity in each region.
- Address operating reserves to meet region-specific needs.
- Consider generator constraints like technology-specific limitations.
- Factor in T&D constraints based on available infrastructure.
- Account for resource constraints by considering spatial and temporal availability of renewable resources [with an hourly submodule for capacity credit calculations].
- And ensure compliance with national, provincial, and local policies related to clean energy objectives, emissions constraints, and incentives.
- Exploring a multitude of pathways to harness energy storage as a Transmission and Distribution [T&D] build out deferral asset.





Schematic of the Lumin Plus™ model structure

Objective of Lumin Plus™

The goal of the Lumin Plus™ AI Engine is to minimize both the capital and operating costs associated with power systems for our clients and partners. This includes reducing:

- The net present value of the cost of adding new generation, storage, as well as T&D capacity.
- The present value of operating expenses over the evaluation period [e.g., expenditures for fuel, operation and maintenance (O&M)] for all installed capacity.
- The cost of various categories of ancillary services.
- The cost or incentive applied by any policies that directly charge or credit [storage as generation] or capacity.
- Penalties for rapid capacity growth, serving as a proxy for manufacturing, supply chain, and siting/permitting limitations.

Storage Technology Blend

Lumin Plus™ benchmarks the competition among numerous electricity generation, storage, and T&D alternatives by pinpointing the most economical energy storage blend of technologies to fulfill power demand needs. This determination is grounded in considerations such as grid reliability [reserve] requirements, technology resource limitations, and policy restrictions.

The process of minimizing costs is carried out in a sequential manner, focusing on two-year intervals starting from 2009. While simulations usually reach resolution in the 2050 solve year, the newly introduced input data extension framework empowers Lumin Plus™ to extend its operations to as far as a 2099 solve year.

Results

Lumin Plus™ generates key results, encompassing details such as the quantity and whereabouts of generator capacity, annual generation from each technology, expansion in storage, T&D, overall costs in the electric sector, electricity pricing, fuel demand and prices, energy equity and justice as well as a whole range of emissions. Subsequently benchmarking these technologies with a diverse range of energy storage innovations.

The amalgamation of these weather datasets provides a comprehensive strategy for weather forecasting, enhancing our capability to refine the integration of renewables with increased precision and reliability. By leveraging these datasets, we can better anticipate and respond to dynamic atmospheric conditions with heightened accuracy and dependability.

Weather Forecasting

Lumin Plus™ models the load and ensures operational reliability through a reduced-order dispatch across 18 time slices within each model year.

Each of the four seasons is portrayed by a representative day featuring four chronological time slices: overnight, morning, afternoon, and evening. The 17th and 18th time slices are summer and winter "superpeaks" representing the top 40 hours of summer and winter loads.

While this schedule enables the model to capture seasonal and diurnal variations in demand, wind, and solar profiles, it falls short in addressing some of the challenges associated with shorter time-scale issues like unit commitment and economic dispatch, particularly in -scenarios with high penetration of variable generation [e.g., wind and solar].

To provide a more accurate representation of how renewable grid integration influences investment and dispatch decisions, the Lumin Plus™ model incorporates parameters designed to tackle intra-time-slice variability and uncertainty in wind, solar, and other variable renewable resources.

The integration of datasets going back some 20 years from a variety of Earth-observing weather satellites enriches the precision and reliability of weather forecasting models. Instruments on these satellites play a crucial role in monitoring diverse parameters, including land surface temperature, cloud cover, vegetation, and aerosols. This diverse dataset offers valuable insights into regional weather patterns and seasonal variations, contributing to a holistic approach to weather forecasting.

Storage Technologies

The major cutting-edge thermal generating storage technologies represented in Lumin Plus™ include; latent heat, thermal battery, sensible heat storage and heat battery.

In addition to representing these technologies, Lumin Plus™ characterizes many renewable technologies, including geothermal, hydropower, biopower, wind, and solar as they are firmed up with storage.

Energy storage technologies within the power sector include: pumped storage hydropower [PSH], compressed-air energy storage [CAES], CSP with thermal storage, Flow Battery, Hybrid Flow Battery, Liquid CO2, Static Battery, Gravity-based PS as well as Lithium based.

Distributed Generation & Virtual PowerPlants

With a comprehensive system-wide, end-to-end, central-planner perspective, Lumin Plus™ is equipped to assess - decisions related to the adoption of distributed generation.

In the case of distributed generation, the analysis within Lumin Plus™ is supported by the BTM Storage Forecaster & EV Adoption Modules—a suite of market-penetration modules adept at generating scenarios depicting the market uptake of [distributed rooftop photovoltaics [PV], distributed wind], fortified with storage.

Lumin Plus™ utilizes these modules to scrutinize adoption scenarios and externally specify the quantity and locations of new distributed generation. The structure of Lumin Plus™ comprises a series of individual yet interconnected optimization problems, each representing a two-year period from 2010 to a maximum end year of 2099.

Every Lumin Plus™ scenario commences with an infrastructure base that reflects installed generation and transmission capacity as of 2011.

Retirements & Additions

In the Lumin Plus™ system, new infrastructure that comes online or is decommissioned throughout the period is incorporated or removed in the respective model year. Generators with scheduled online dates are included as planned builds in future years, while scheduled retirements are set to be phased out from the fleet as appropriate.

Furthermore, Lumin Plus™ inputs include an equipment lifetime for each technology, determining the retirement of capacity as it ages. In specific scenarios, existing stock may be underutilized due to factors such as high fuel prices or stringent emissions standards.

To address this, Lumin Plus™ enables "economic" retirements of underutilized coal capacity if its usage [capacity factor] falls below a certain threshold.

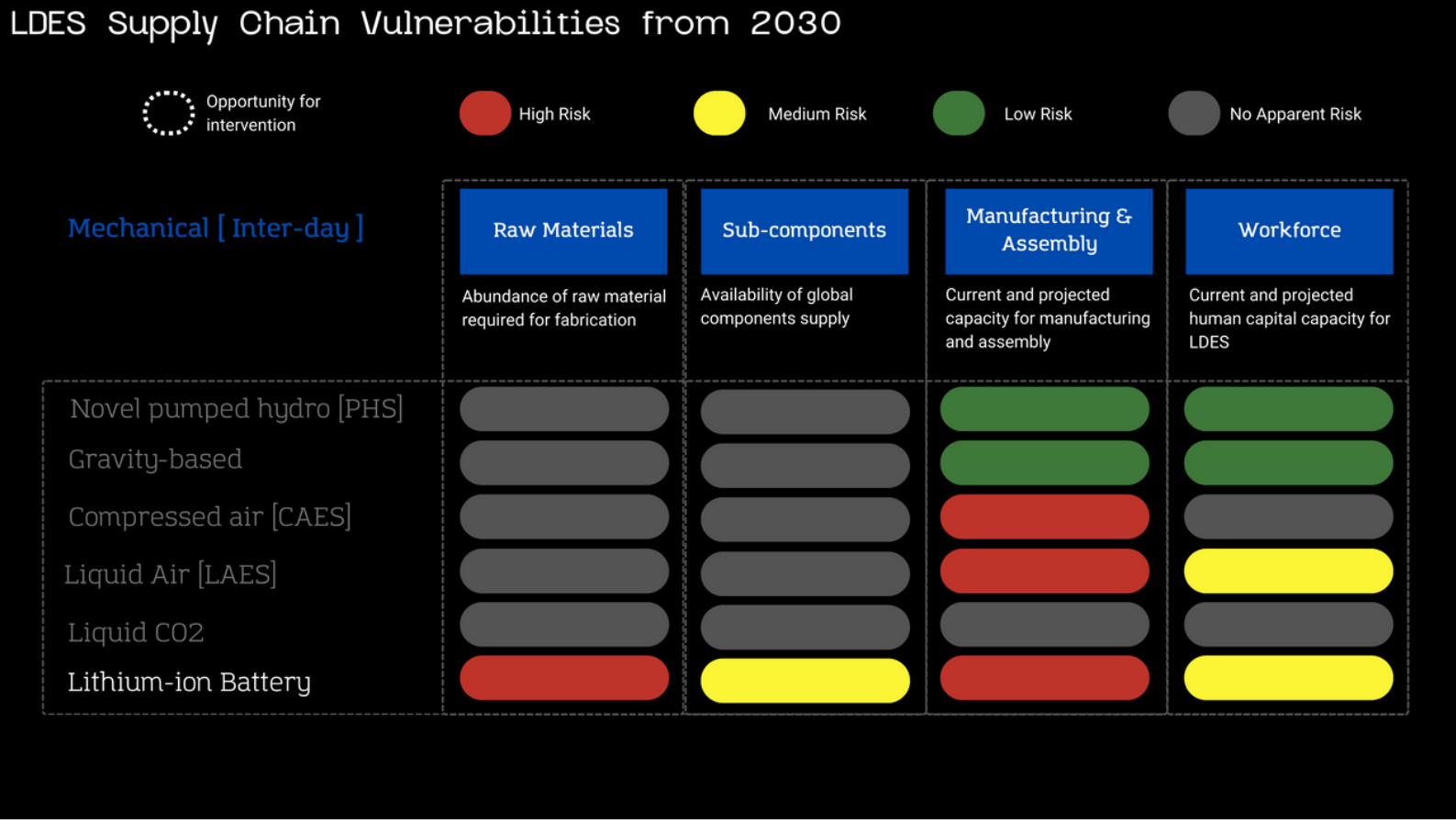
Leveraging advanced calculations and data analysis, the engine quantifies the multitude of benefits associated with the transition from coal, encompassing crucial factors such as pollution reduction, job creation opportunities, and improved system reliability.

Emissions

Lumin Plus™ monitors emissions of six major greenhouse gases, namely Carbon Dioxide [CO2], Sulfur Dioxide [SO2], Nitrogen Oxides [NOx], Mercury [Hg], Methane [CH4] Sulfur Hexafluoride [SF6], Hydrofluorocarbons [HFCs], and Perfluorocarbons [PFCs] from all technologies.

LifeCycle Analysis

Lumin Plus™ CarbonQuants™ is an integrated feature that utilizes data and analysis derived from CarbonQuants™, our engine dedicated to measuring, reporting, and verifying CO2 emissions throughout the entire value chain of energy storage technologies, that is from 'cradle to grave.' This integration allows us to compare the lifecycle emissions of different storage technologies as we construct comprehensive long-term deployment scenarios for power markets.

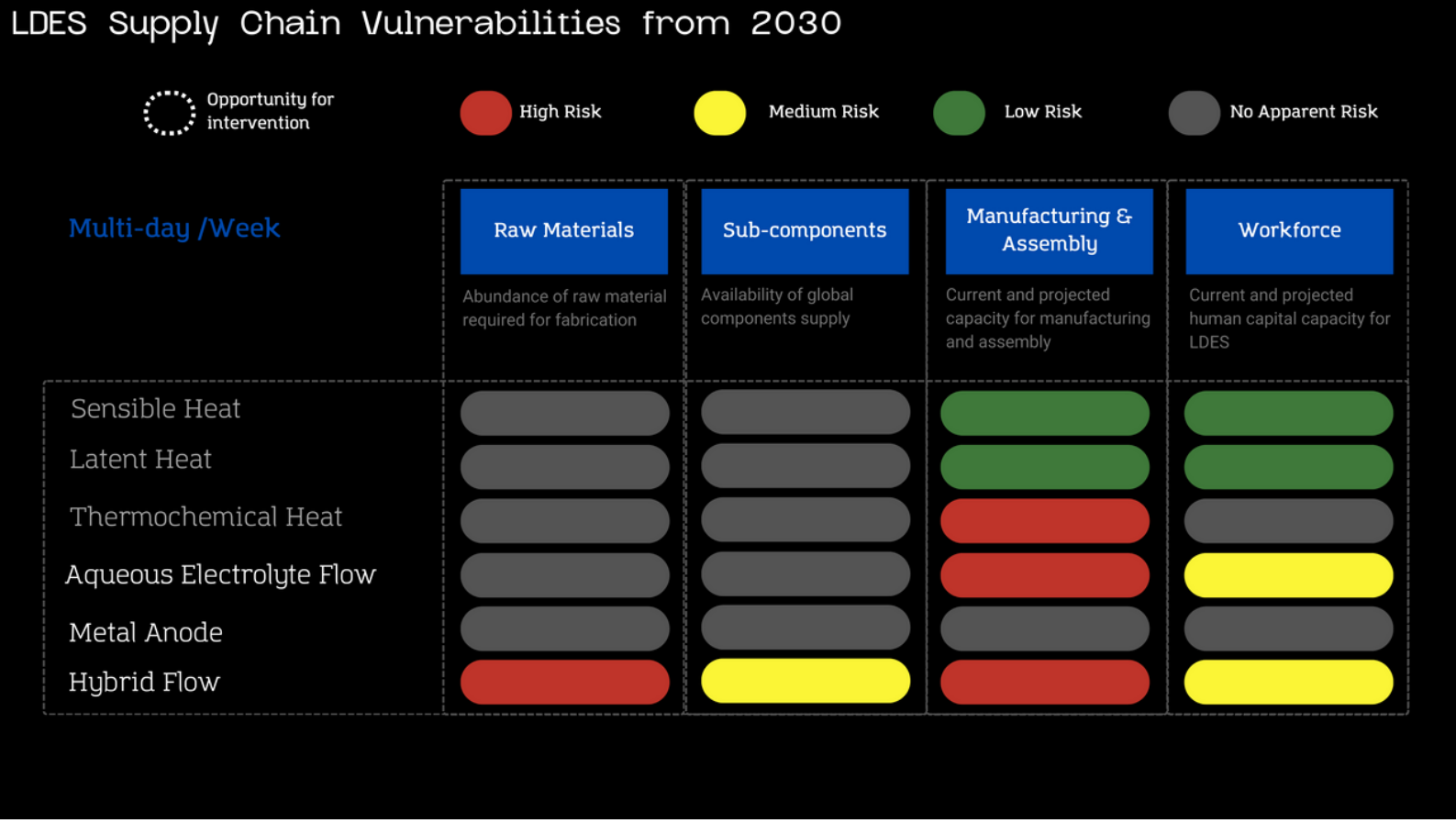


Supply Chains

Lumin Plus™ integrates with ChainSynQ™ to benchmarks storage technologies based on supply chain infrastructure and how they can scale significantly to meet the large scale deployments needed in the decades to come as renewable penetration increases.

Inter-day Storage

As indicated in the table above, Inter-day LDES systems exhibit fewer vulnerabilities in the supply chain compared to Li-ion alternatives. This includes factors such as the availability of components, operational manufacturing capacity, the presence of highly skilled and specialized talent for design and technical components and systems, as well as skilled [likely unionized] talent for construction and operations.



Multi-day Storage

Yet, when examining Multi-day/week LDES systems, there exists a moderate level of potential supply chain risks. However, there are opportunities to address and alleviate these risks. This includes considerations for the availability of components, operational manufacturing capacity, the presence of highly skilled and specialized talent for design and technical components and systems, as well as skilled [likely unionized] talent for construction and operations.

Attaining a thorough grasp of the scalability and limitations within the supply chain is essential for long-term planning, especially for our partners aiming to invest substantial capital, given the modular nature of most storage technologies.

This understanding empowers them to adopt a more detailed strategy for scaling, taking into account potential challenges that may arise in the course of their long-term deployment efforts.

SCM Benchmarking

Equipped with a supply chain modeling module, ChainSynQ™ is tailored to identify, evaluate, and benchmark opportunities for minimizing the energy and carbon intensities across the energy storage innovation cycle. It evaluates energy and material inputs not only during the initial manufacturing phases but also across the final production stages. ChainSynQ™ offers insights into the entire manufacturing process, spanning from resource extraction ["cradle"] to the factory gate. And these insights can be leveraged by partners with deep focus on scope 3 emissions.

Cycling & Degradation

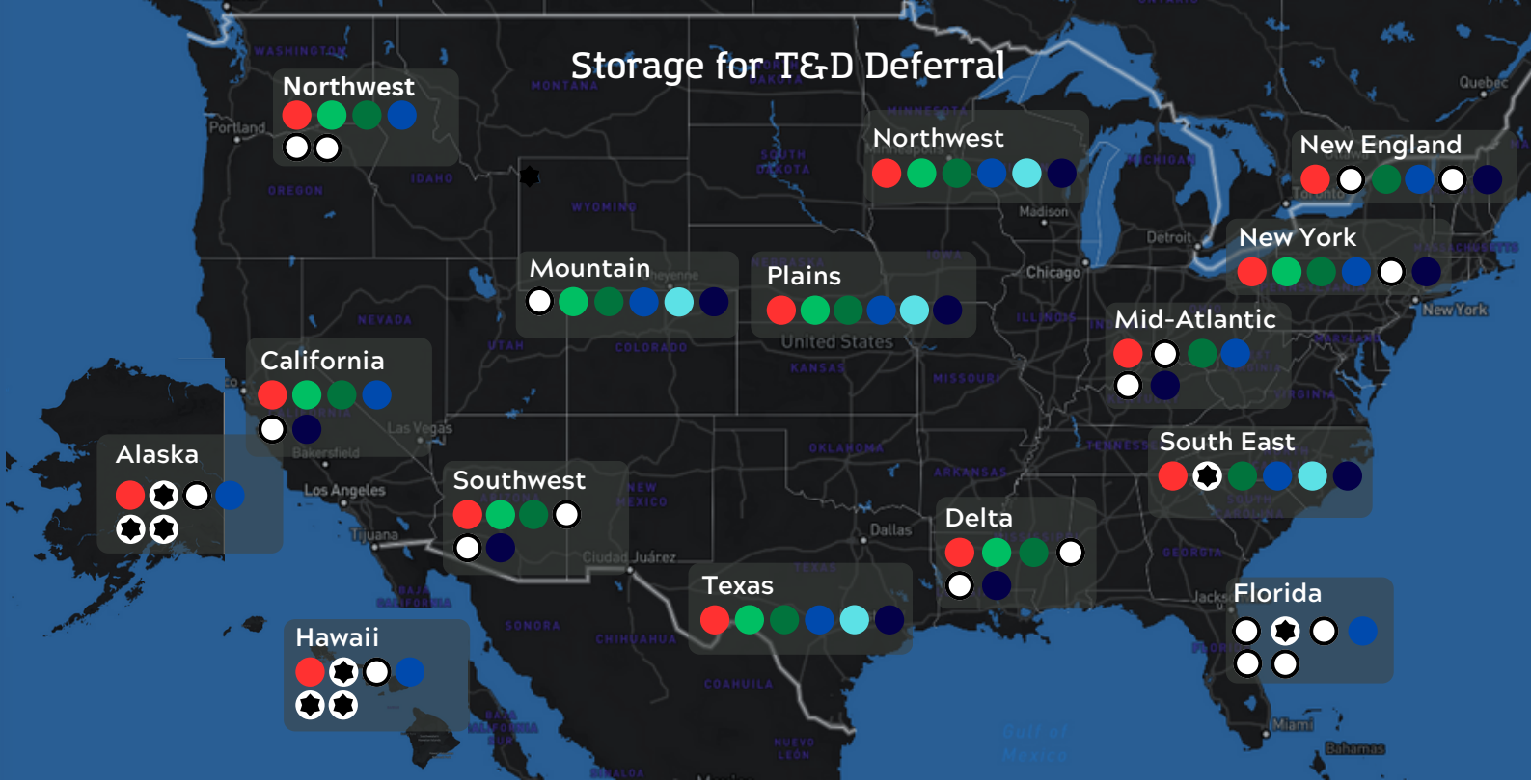
Lumin Plus™, while possessing a robust operations and maintenance module, currently lacks specific considerations for the safety and reliability of energy storage technologies in its capacity planning model.

To enhance the accuracy of projected operations, maintenance costs, and reliability estimates, Lumin Plus™ incorporates our EcoReli™ AI Engine. Integrated seamlessly, EcoReli™ endeavors to quantitatively assess the safety and reliability of energy storage systems, incorporating benchmarking data into the capacity planning engine. This integration aims to deliver a comprehensive and precise estimation of costs associated with the technology.

EcoReli™ boasts benchmarking capabilities that extensively evaluate safety and reliability across various dimensions. These include scrutiny of battery cycling, examination of cell testing data where accessible, assessment of thermal performance, and analysis of degradation factors. The comprehensive coverage in these areas ensures a thorough evaluation of the safety and reliability aspects of energy storage technologies.

Storage Technology Benchmarking

Lumin Plus™ additionally evaluates storage technologies by benchmarking their potential learning curves derived from research and development endeavors. This assessment considers both the existing and potential cost performance, encompassing possible cost reduction resulting from manufacturing innovations across all emerging storage technologies.

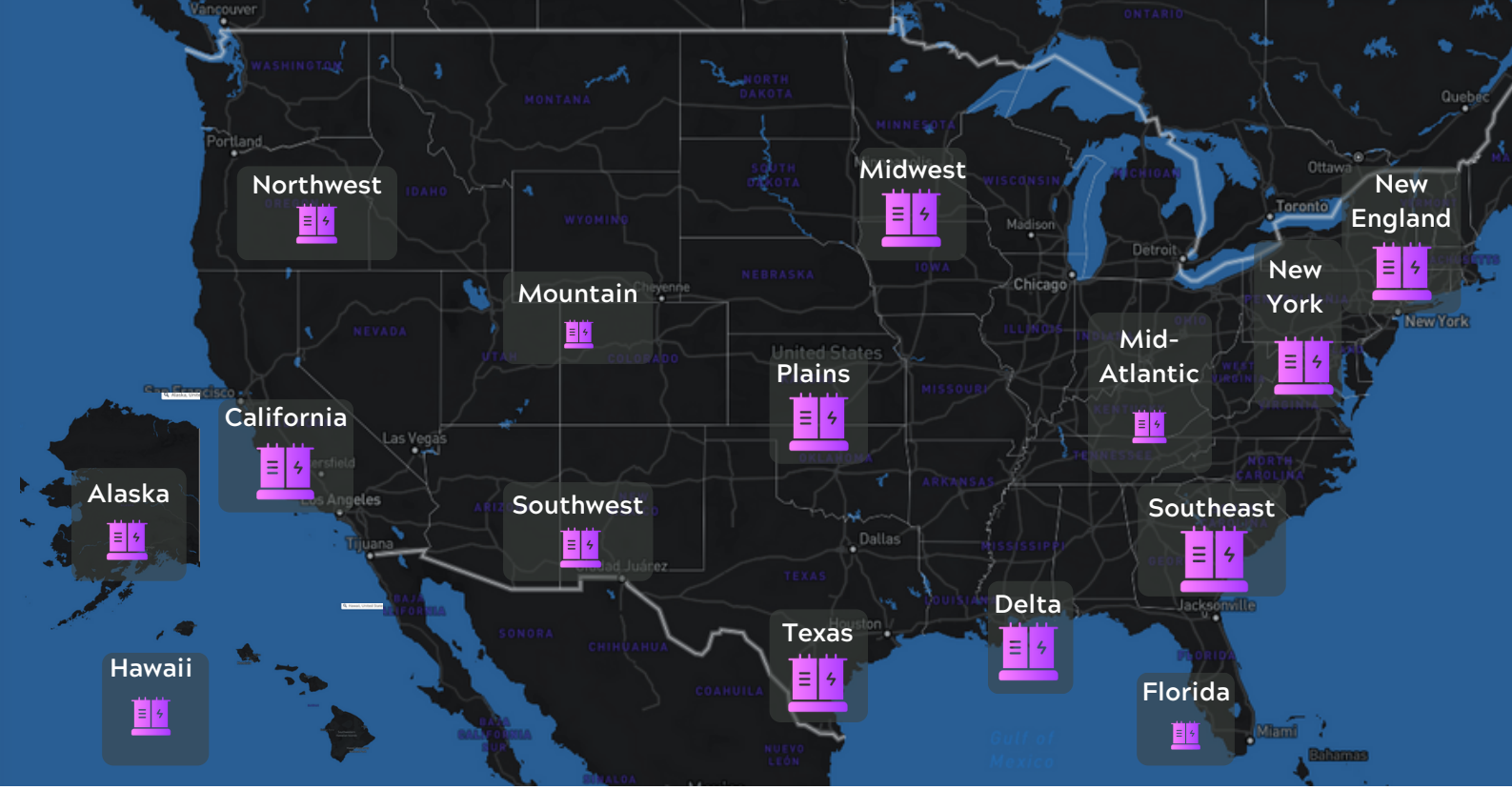


		California	Northwest	Mountain	Southwest	Texas	Pains	Midwest	Delta	Southeast	Florida	Mid-Atlantic	New York	New England	Alaska	Hawaii
Current or Anticipated Need	Improve reliability & resilience	●	●	○	●	●	●	●	●	●	○	●	●	●	●	●
	Alleviate congestion & unscheduled flows	●	◉	◉	◉	●	●	●	●	◉	◉	○	●	○	◉	◉
	Alleviate transfer capacity limits between neighbors	●	●	●	●	●	●	●	●	●	○	●	●	●	○	○
	Deliver cost-effective generation to meet demand	●	●	●	○	●	●	●	○	●	●	●	●	●	●	●
Anticipated Need	Meet future generation & demand with within-region transmission	○	○	●	○	●	●	●	○	●	○	○	○	○	◉	◉
	Meet future generation & demand with interregional transfer capacity	●	○	●	●	●	●	●	●	●	○	●	●	●	◉	◉

T&D Needs

Lumin Plus™ has a Transmission & Distribution [T&D] deferral module which relies on current and anticipated T&D requirements. It conducts an analysis of both historical and expected electric T&D needs, defining these needs as instances where there are present or anticipated capacity constraints or congestion in a given geographic area.

Regions experiencing T&D needs stand to benefit from upgraded, uprated, or new T&D facilities, including alternative solutions. These improvements aim to enhance the reliability and resilience of the power system, alleviate T&D congestion and unscheduled flows, address power transfer capacity limits between neighboring regions, provide cost-effective generation to meet demand, and satisfy projected future generation, electricity demand, or reliability requirements as noted in the illustrations above.



Model Functionality

Lumin Plus™ incorporates an array of power system models, both long-term and short-term, to assess various storage options for scenarios involving T&D needs indicated in the previous page. The objective is to inform existing planning processes by demonstrating how storage can effectively reduce and or deferrer some T&D buildout capital expenditure. Additionally, the model evaluates storage as T&D deferral alternatives beyond current planning parameters, providing a comprehensive set of economic, reliability, and resilience indicators for each T&D deferral scenario.

The model operates by validating the viability of upcoming scenarios through the imposition of physical constraints. It acquires insights into grid balancing through enhanced spatial and temporal modeling, scrutinizing the operation of the T&D system across various times of the day and seasons. These observations coalesce into multiple pathways illustrating how storage addresses these constraints throughout different periods—day, week, month, and year.

Consideration of Land Use

The model considers T&D permitting and siting ordnances, and explores various pathways to harness storage as a potential solution to address some of these setbacks.

Economic Outcomes

Incorporating EquiPower™ into the system enables the examination of energy storage-specific economic outcomes, encompassing factors such as jobs, earnings, value added, and total output, within Lumin Plus™.

Presently, linkages have been established for specific technologies—land-based wind and photovoltaics coupled with storage—confining economic results to these technologies alone.

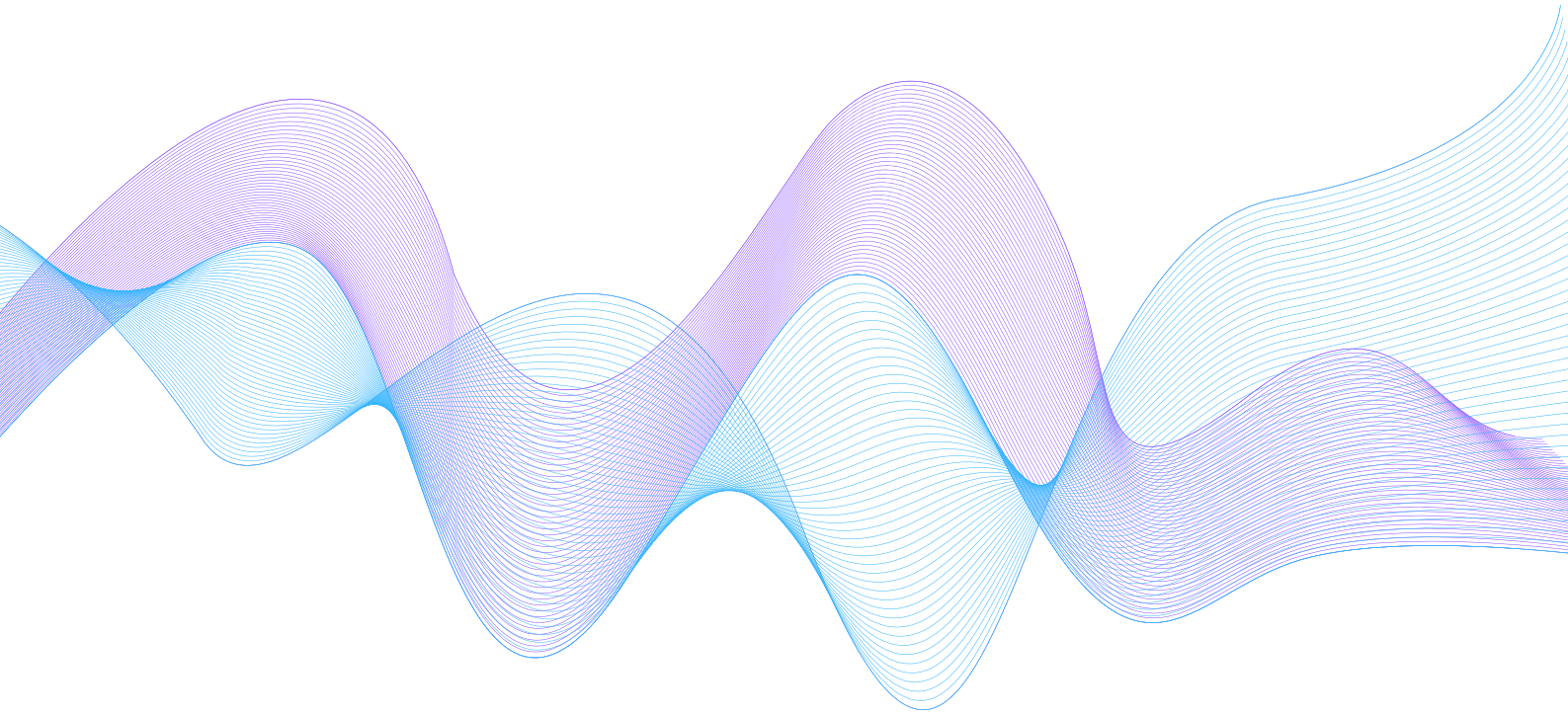
Lumin Plus™ outputs, including capacity, generation, fuel use, capital cost, O&M cost, and fuel cost by BA, are processed through the EquiPower™ engine to generate comprehensive multi-level economic results.

By also considering the health benefits, skill development, and job creation opportunities, we can gain a more comprehensive understanding of the social implications of transitioning away from fossil based power and EquiPower™ seeks to do just that.

Areas With Burdens

The EquiPower™ tool also features an interactive map and utilizes datasets as indicators of burdens across numerous categories: climate change, energy, health, housing, legacy pollution, transportation, water and wastewater, and workforce development.

Leveraging this information, the tool identifies communities that bear these burdens, categorizing them as disadvantaged due to being both overburdened and underserved.

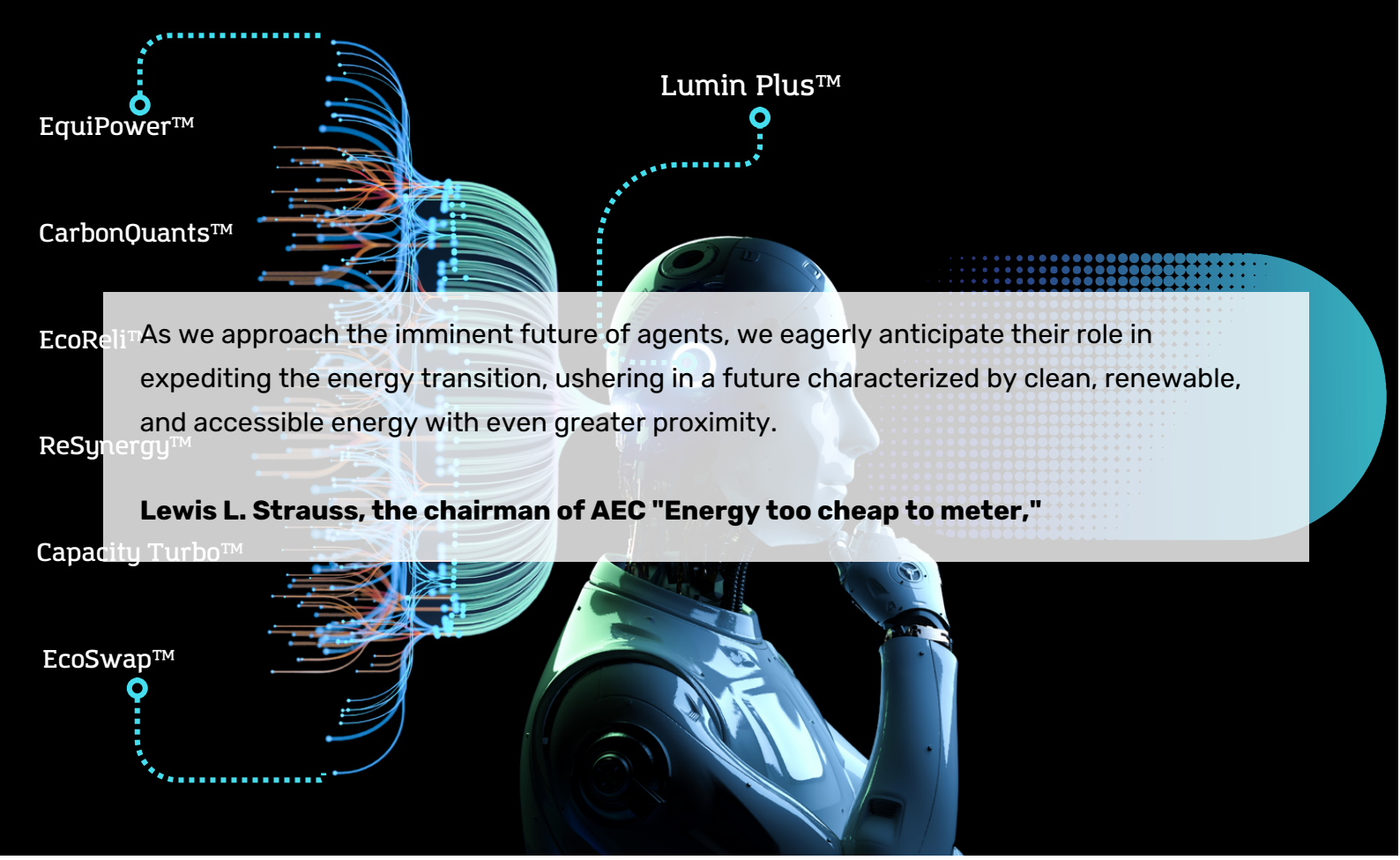


Conclusion

In conclusion, Lumin Plus™ not only possesses expertise in power systems planning but also maintains a specific focus on benchmarking LDES against the predominant utility-scale energy storage technologies, such as Lithium-Ion Batteries. This focused approach aids our partners in enhancing the accuracy of their estimates and long-term planning for capacity expansion, thanks to our robust weather computation capabilities.

Lumin Plus™ comprehensively understands LDES technologies across various categories, including chemical, mechanical, electrochemical, and thermal. Through its Virtual Power Plant [VPP] module, Lumin Plus™ seamlessly - integrates distributed energy resources into the capacity planning process. The engine also accounts for the technology scaling fundamentals of each storage technology, considering potential R&D improvement efforts in technology, manufacturing, and supply chains.

Where Lumin Plus™ excels is in providing fundamental insights into emissions from various technologies, particularly through our CarbonQuants™ engine. This capability enables the computation and integration of lifecycle analysis. Furthermore, Lumin Plus™ is inherently attuned to the present energy transition landscape in terms of equity and justice. Through integration with EquiPower™, it can compute long-term planning scenarios for each renewable energy deployment pathway with energy equity and justice in consideration.



As we approach the imminent future of agents, we eagerly anticipate their role in expediting the energy transition, ushering in a future characterized by clean, renewable, and accessible energy with even greater proximity.

Lewis L. Strauss, the chairman of AEC "Energy too cheap to meter,"

The Future

In the upcoming era, the need to use various applications within a suite for distinct tasks will be a thing of the past. With Lumin Plus™, you will effortlessly convey your intentions in everyday language, whether it involves energy equity, lifecycle analysis, recycling and supply chain, reliability benchmarking and analysis, coal power replacement.

Based on the extent of information shared, the engine will provide specific responses, benefitting from a profound understanding of your goals. In the near future, users of our application will enjoy an artificial intelligence-powered assistant that surpasses present day capabilities.

This innovative AI, known as an agent, responds to natural language and performs diverse tasks by drawing on its knowledge of energy storage.

The concept of agents is the foundation of our company since 2017, however we were a little bit ahead of our time. Recent strides in AI, such as Chat GPT, have made agents a practical reality.

Agents are poised to transform how individuals interact with computers and revolutionize the software industry, marking the most significant shift in computing since the transition from command typing to icon tapping. This transformative vision has led us to collaborate with Microsoft, for a NetZero Co-Pilot, employing our lifecycle management approach for emerging energy technologies.