



THE MOST **RELIABLE, LONGEST-LASTING**  
**VANADIUM FLOW** BATTERY IN THE WORLD

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[WWW.VRBENERGY.COM](http://WWW.VRBENERGY.COM)

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## ABOUT VRB ENERGY

VRB Energy is a fast-growing, global clean technology innovator. We have developed the most reliable, longest-lasting vanadium flow battery in the world, with over 750 MWh of systems deployed and in development, and over 1,000,000 hours of demonstrated performance. VRB Energy is the technology leader in the field, and the combination of our proprietary low-cost ion-exchange membrane, long-life electrolyte formulation and innovative flow cell design sets us apart from other providers.

Our vanadium redox batteries (VRB®) store energy in liquid electrolyte in a patented process based on the reduction and oxidation of ionic forms of the element vanadium. This is a nearly infinitely repeatable process that is safe, reliable, and non-toxic. Components can be nearly 100% recycled at end-of-life, dramatically improving lifecycle economics and environmental benefits compared to lead-acid, lithium and other battery systems.

## VRB ENERGY OWNERSHIP

VRB Energy is 90% owned by Ivanhoe Electric Inc., a United States minerals exploration and development company with a focus on developing mines that can deliver the critical metals necessary for electrification of the economy. For more information on VRB Energy please visit our website at [www.vrbenergy.com](http://www.vrbenergy.com).



# STORAGE IS ENABLING THE RENEWABLE ENERGY REVOLUTION



## RENEWABLE ENERGY INTEGRATION

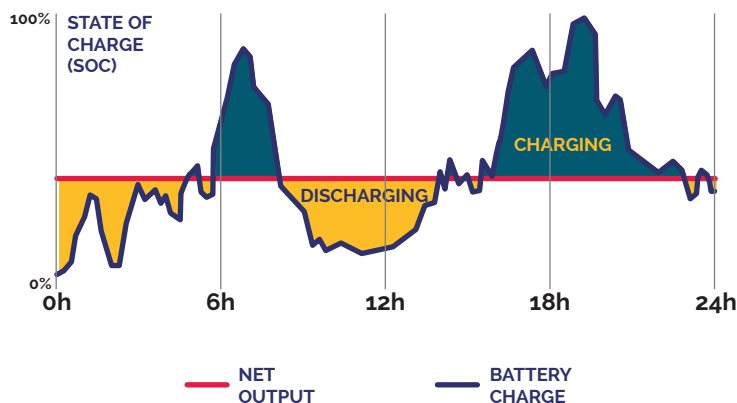
More energy from the sun reaches the earth in a single hour than humanity uses in an entire year. Photons hit the silicon in a solar panel and dislodge electrons as an electric current. The sun's rays also warm the earth, causing air to rise and generating wind currents that we can harness with wind turbines.

We can capture this variable energy with energy storage, and convert this free fuel into nearly limitless clean electricity. VRB Energy's Vanadium Redox Battery Energy Storage Systems (VRB-ESS®) are ideally suited to charge and discharge throughout the day to balance this variable output of solar and wind generation.

VRB-ESS are a type of flow battery, which are poised to dominate the utility-scale storage market for wind and solar integration. The technology is

fundamentally better suited to these deep discharge applications that require four to eight hours of storage per day. VRB-ESS deliver an almost infinite number of cycles over more than 25 years, yielding the best, most sustainable lifecycle economics.

STORAGE SMOOTHS VARIABLE WIND OUTPUT  
TO KEEP THE GRID STABLE



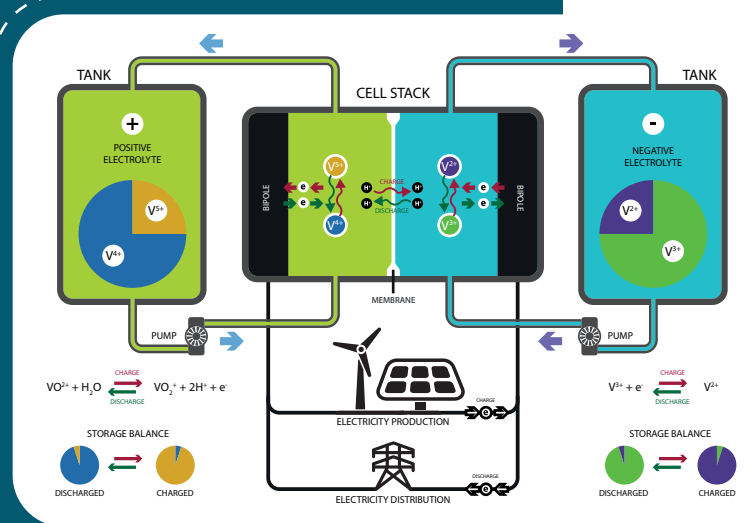
PROPRIETARY **LOW-COST** ION-EXCHANGE  
MEMBRANE, **LONG-LIFE** ELECTROLYTE  
FORMULATION, **INNOVATIVE** FLOW CELL DESIGN

## PRODUCT PERFORMANCE

### MODULAR DESIGN

The standard VRB-ESS Power Modules, contain a series of cell stacks, pumps, and controls in a containerized format, combined with electrolyte storage tanks and power conversion systems.

VRB SCHEMATIC



### MW-CLASS

Based on a 500kW containerized module, these systems are typically 1 MW / 4 MWh up to 100 MW / 800 MWh in size installed at utility, commercial and industrial sites, in support of solar or wind farms, or in isolated microgrids.

GW-class systems are also available on a custom-engineered basis.



AN ALMOST **INFINITELY REPEATABLE** PROCESS

**SAFE, RELIABLE, NON-TOXIC**

VIRTUALLY **100% RECYCLED** AT END-OF-LIFE

## APPLICATIONS

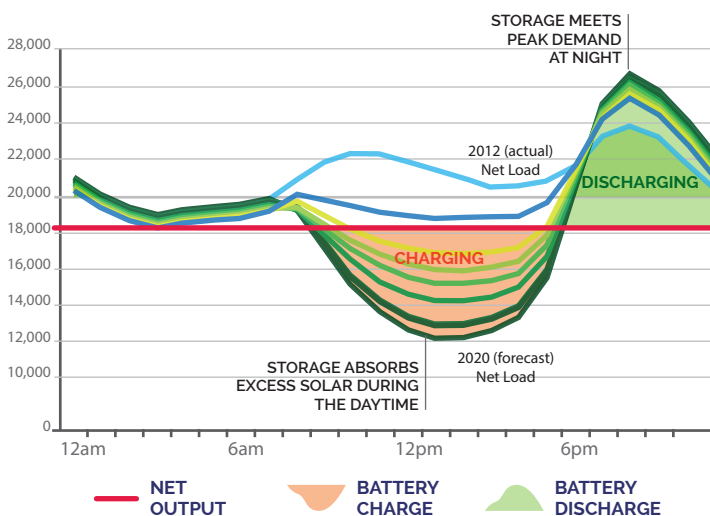
### UTILITY OPTIMIZATION

#### Peaker Plant Replacement and T&D Deferral

VRB-ESS can respond to grid conditions within ½ cycle, providing frequency and voltage support in real time, while simultaneously serving longer-duration energy needs.

VRB-ESS enable utilities to balance loads, make more efficient use of existing infrastructure and operate smart microgrids. VRB-ESS can replace peaker plants, and investments in transmission and distribution (T&D) can be deferred.

*Example: Net system load in California drops dramatically mid-day due to increasing solar penetration. Storage is needed to balance and stabilize.*



SOURCE: CALIFORNIA CAISO

### COMMERCIAL AND INDUSTRIAL (C&I)

#### On-Site Energy Optimization

Installed "behind-the-meter" at C&I facilities, VRB-ESS reduce operating expenses through multiple benefit streams:

- Reduction of peak demand charges from utilities.
- Integration and optimization of on-site renewable energy.
- Provision of backup power that reduces losses in the event of utility outages.
- Reduction of wear on equipment through improvement of power quality.

### MICROGRIDS

#### System Balancing and Energy Optimization

Microgrids combine a diverse set of generation and loads on a system isolated from the main utility grid. They are typically either remote, islanded systems or special zones designed to connect or disconnect from the main utility grid for economic or power quality reasons.

On isolated diesel grids, VRB-ESS balance loads, maintain power quality, and reduce fuel use. On grid-connected systems, VRB-ESS allow seamless connect/disconnect from the main utility grid on-command. With the dramatically reduced cost of solar power, the combination of photovoltaics and VRB ("PV + VRB") is now three to five times cheaper than traditional diesel generation.

# CHINA STATE GRID'S ZHANGBEI DEMONSTRATION SITE, THE **LARGEST FLOW BATTERY** FOR THE **LARGEST UTILITY IN THE WORLD**



## SOLAR-WIND-STORAGE DEMONSTRATION PROJECT AT 2 MW X 8 MWH

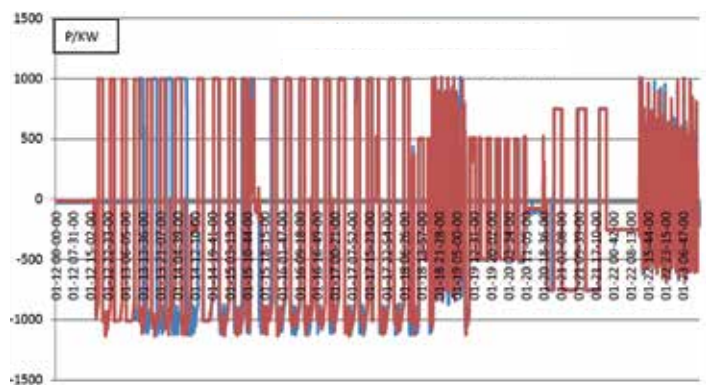
VRB Energy has completed the rigorous acceptance testing and approval process administered by State Grid Corporation of China, the world's largest electric utility company.

The 8 MWh VRB-ESS installed at State Grid's cutting-edge 500 MW solar-wind-storage project in Zhangbei (which helped supply 100% clean energy for the 2022 Winter Olympics) achieved all of the performance test requirements for:

- Renewable Smoothing
- Frequency Regulation
- Peak Shifting
- Microgrid Support

The system achieved 100% availability during the rigorous 240-hour acceptance test, and has since demonstrated over 10 years of reliable performance.

Two 1 MW units, Co10 (red line) and Co11 (blue line): power-time curve throughout the 240 hour test.



## PERFORMANCE EXCEEDED EXPECTATIONS ACROSS ALL MAJOR METRICS:

<b>AVAILABILITY:</b>	100% of Test Hours
<b>POWER RATING:</b>	120% of Target
<b>EFFICIENCY:</b>	110% of Target
<b>RESPONSE TIME:</b>	< 20 ms Target

# LOWEST LIFECYCLE COST OF ENERGY (LCOE) WITH PROVEN PERFORMANCE AND SAFETY

## ENVIRONMENTAL BENEFITS

Air emissions from fossil-fuel fired power generation plants are a major source of environmental degradation worldwide, and air pollution has significant costs in terms of human health. Solar and wind energy are now widely recognized as the lowest cost of power generation in most locations around the world; however they cannot always meet all peak energy demand.

California alone, still utilizes natural gas to meet nearly one third of its electricity demand, while at the same time renewable resources are often curtailed in periods of low demand .

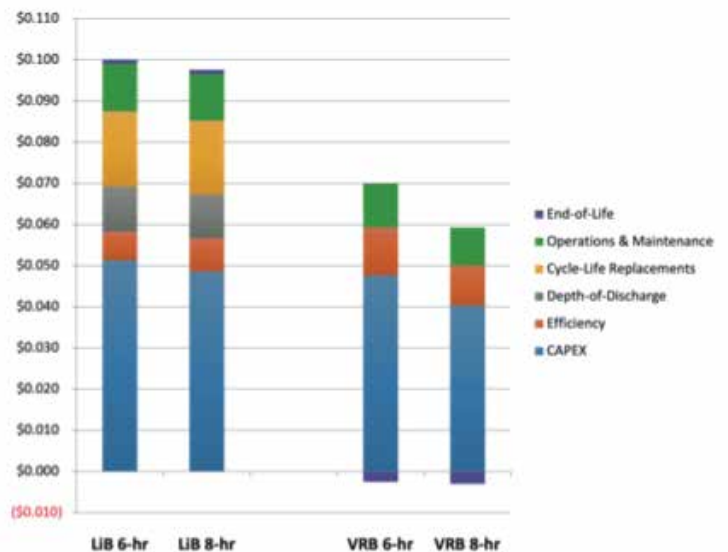
By utilizing VRB-ESS, solar and wind energy can be stored and discharged to meet peak energy demand, ensuring that the clean power is not wasted.

Adding VRB-ESS equal to 20% to 50% of the capacity of a typical wind or solar farm can optimize the use of "free" and clean energy, helping reduce global carbon dioxide emissions and harmful local air pollution.

## LIFECYCLE BENEFITS

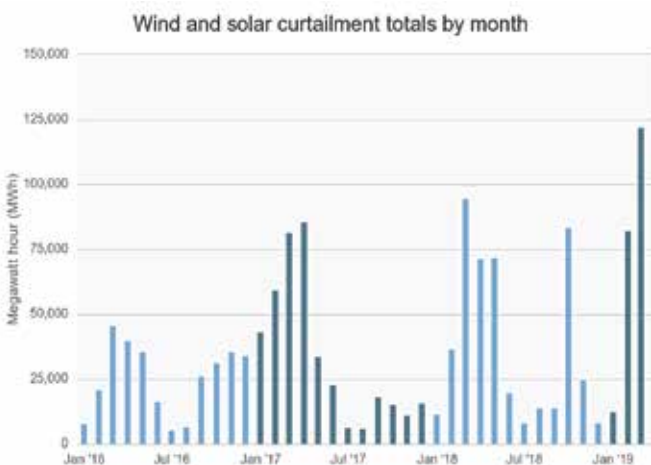
VRB Energy's proprietary all-vanadium electrolyte is the same on both the positive and negative sides of the battery. It is safe, non-combustible, and never wears out. At the end of 25 or more years of project life, the electrolyte can be reused in another battery, or recycled; and the other components can be recycled. This helps lower lifecycle costs and is a significant environmental benefit compared to other types of battery systems.

### Levelized Cost of Energy (LCOE) \$/kWh



The above comparison is based on Bloomberg and VRB Energy estimates for 2023, assuming one cycle per day, a 25-year project life, LiB replacement in year 10 at 50% of original cost, and a 5% discount rate.

The up-front capital costs for lithium batteries (LiB) is not an accurate metric for value, as it does not include replacement costs after 2,000 – 4,000 cycles, depth-of-discharge limitations imposed by warranty terms (typically resulting in a loss of 20% of capacity), or end-of-life disposal costs (recycling will always be more expensive compared to the high residual value of vanadium).



# VRB ENERGY IS THE **TECHNOLOGY LEADER** IN THE FIELD



## **ECONOMICS**

Lithium-based batteries have inherently shorter lifetimes and are not well suited for longer duration storage (4+ hours). Vanadium outperforms lithium on depth-of-discharge (DoD), cycle life, and end of life value (lithium carries a disposal cost). VRB-ESS are two to three times lower in LCOE.



## **PROPRIETARY TECHNOLOGY**

VRB Energy is the technology leader in the field. The combination of our proprietary low-cost ion-exchange membrane, long-life electrolyte formulation and innovative flow cell design sets us apart from other providers.



## **SAFETY**

Unlike other large battery systems, VRB-ESS contain no heavy metals such as lead, nickel, zinc or cadmium. The liquid electrolyte is non-toxic, non-flammable and is 100% reusable. VRB-ESS operate at low temperature and pressure and are an inherently stable and safe design.



## **PROVEN PERFORMANCE**

With over 1,000,000 hours of operation, and millions of cycles on systems in our R&D labs and in the field, VRB Energy has the most proven technology and reliable products in the industry today.



## **SYSTEM QUALITY COMPLIANCE**

VRB-ESS have been reviewed and are in compliance with European system quality and safety guidelines.



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