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FLOW BATTERIES
HIGH-CAPACITY SCALABLE ENERGY STORAGE

LAST MILE DELIVERY

FLOW BATTERIES: HIGH-CAPACITY SCALABLE ENERGY STORAGE

INTRODUCTION

As renewable power penetration increases, supply and demand balancing becomes harder to manage as power generation fluctuates. Smaller natural gas power plants, also known as peaker plants, can top up the base-load capacity to meet demand spikes, but comparatively high costs and emissions are slowly seeing a phase out of natural gas. Battery storage can be an alternative to peaker plants, and flow batteries are one option that offer the scale and cycle-life for carbon-free bulk capacity to the grid. Flow batteries store energy in molecules dissolved in a liquid electrolyte contained in large tanks, unlike conventional batteries that store energy in a solid cathode and anode. Despite high capital costs, flow batteries enable easier scaling of energy-storage systems for large capacities and long discharge durations – ideal properties to integrate base-loads of renewable energy to the grid.

FLOW BATTERIES: HIGH-CAPACITY SCALABLE ENERGY STORAGE

Unique selling proposition

Utility-scale stationary energy storage generated around US$7 billion in revenue in 2019, with 15 gigawatt hours (GWh) of installed capacity. The sector is on track to exceed over 150 GWh installed capacity by 2035, to support an extensive global renewable energy infrastructure generating over 5,000 terawatt hours (TWh) of electricity per year. The long discharge times and vast storage volumes flow batteries can help enable are essential to support power grids reliant for the bulk of their base-load power on renewable sources.

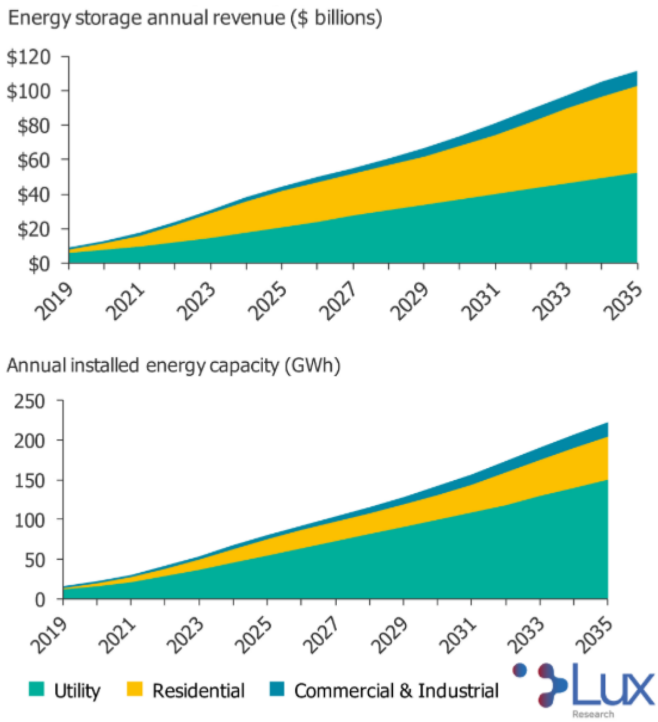

Figure 1. Global stationary energy storage market forecasts (a) revenue in USD (b) installed capacity in GWh.
Source: Lux Research

The unique feature of flow batteries is that they store energy in liquid-phase electrolytes, with power generated in a cell where the two electrolyte liquids meet, separating storage capacity from discharge power. Unlike conventional batteries, where both more power and capacity require more expensive-to-produce electrode material, a flow battery can be easily scaled by increasing the volume of the electrolyte tanks. Flow batteries also have a high degree of stability, with system lifespans often well above 10 years and over 10,000 cycles.

Flow batteries do have relatively low round-trip efficiencies of 65-75 percent, high capital costs, and large footprints due to low energy densities of 15-35 Wh/L. A number of variants of the well-established vanadium redox system have entered the market in recent years, with more favorable performance and economic profiles, which can aid in wider adoption.

Technology

A typical flow battery consists of two electrolyte tanks, with the electrolyte liquids meeting at the power-producing unit, the power cell. This cell contains two electrode plates divided by a separator, or ion exchange membrane, which facilitates the electrochemical reaction between the positive (catholyte) and negative (anolyte) electrolyte liquids that are pumped through on either side of the cell. The battery is also charged through the power cell, although theoretically it could also be charged by replacing discharged electrolyte liquid.

Flow batteries decouple power from energy capacity, which makes them attractive to tailor both aspects to each specific grid-storage use case. Storage capacity can be scaled by increasing electrolyte volumes, while the power rate is determined by the total surface area of the power cell membrane and hydraulic pump flow rate. Connecting multiple cell stacks in parallel can increase the system power output.

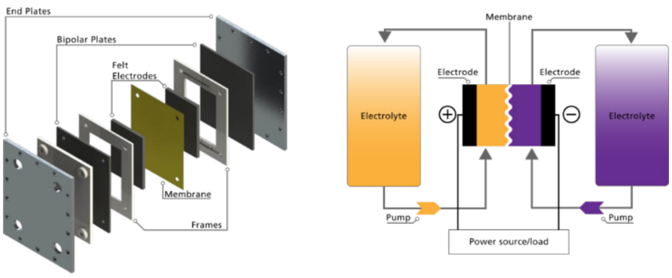

Figure 2. Exploded view and general schematic of a flow battery.
Source: FlowCamp

Flow batteries, particularly redox flow batteries, have various design advantages, including: a flexible system layout (tanks and power stacks are separate components, connecting by piping); long cycle life (due to the lack of solid-to-solid phase transitions of battery electrodes); no harmful emissions; and no need for equalization charging (the overcharging of a battery to ensure all cells have an equal charge). Compared with other batteries, they tend to offer lower maintenance costs and a higher tolerance to over-charging and discharging.

The lack of flammable electrolytes is a key safety feature for use in certain high-risk locations, though toxicity of common electrolytes hinders adoption in other areas – for instance, residential energy storage. Electrolytes can also be stored away from the power stack and pumped over distance, helping to increase safety when operating near chemicals, or fragile or high value infrastructure, and personnel. They can also be left completely discharged for long periods with no adverse effect, due to the single charge state between electrolytes, while the battery suffers no permanent damage if electrolytes are mixed. This contrasts with lithium-ion batteries that are typically damaged when falling below 20 percent charge, leading to functional capacity below the nameplate capacity.

Electrolytes

Commercial options for flow batteries include vanadium and zinc-bromine, though a broad range of variants exist in academia.

Vanadium redox flow batteries (VFRB) exploit vanadium's four different oxidation states in solution, with V^{2+} and V^{3+} ions in the negative half-cell and V^{4+} and V^{5+} ions in the positive half-cell. Because the battery has just one electroactive molecule, it has a high system stability by eliminating the risk of cross-contamination between cells. VFRB is around 30 Wh/L electrolyte, compared to 100 Wh/L for lead acid batteries and 600 Wh/L for Li-ion, resulting in higher costs and system sizes. Electrolyte solutions are vanadium pentoxide (V_2O_5) dissolved in an acid – often sulfuric acid (H_2SO_4), with high electrolyte concentration and reasonable temperature tolerances. Nonetheless, VRFB's have a limited thermal operating range of about 10°C to 40°C that requires temperature control systems, limiting their use in, for instance, microgrids in more extreme climates, where batteries in general can be particularly useful.

Zinc-bromine offers an energy density at least double that of vanadium redox, at 60-120 Wh/L; however, with a cycle life up to two-thirds lower and poorer efficiency, zinc-bromine batteries are roughly on par with VRFB's in overall cost and performance.

Academia has developed various other types of flow cells, including hybrid, single liquid flow (SLIQ), membraneless, organic, metal hydride, metal-organic, nano-network, zinc-cerium hybrid, zinc-bromine hybrid, hydrogen bromine, and semi-solid. Although some offer better performance than incumbents, most are unlikely to prove economically feasible, due to reliance on rare elements or aggravated engineering challenges present even in commonly available variants.

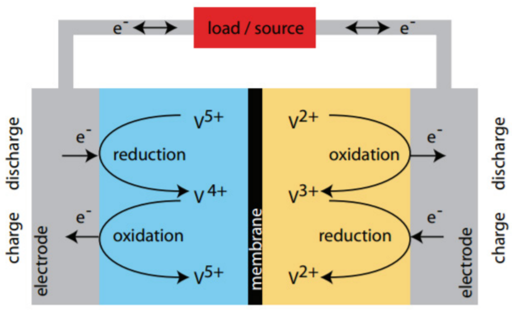

Figure 3. Vanadium redox flow battery charge and discharge process.
Source: CDN

Membranes

Membranes facilitate ion-exchange across the cells. This critical component can comprise around 30 percent of total system costs and is one of the main determinants of economic viability. Ideal characteristics include high ion selectivity and permeability, low cost, low electrical resistance, good mechanical properties, and resistance to the highly oxidizing positive half-cell electrode.
Nafion is a perfluorosulfonic acid (PFSA) polymer proton exchange membrane (PEM), developed by **DuPont** in the late 1960s, with a stable perfluorinated backbone (similar to Teflon) with acidic sulfonic groups. Its high cation conductivity, chemical resistance, selectivity, high water permeability, and thermal and mechanical stability has made it the primary membrane material despite its high costs.

Figure 4. Rolls of Nafion, used in flow battery membranes.
Source: Nafion

Stack/battery design

Stacks are systems comprised of two or more cells, with novel designs able to reduce their size and improve storage capacity relative to system footprint. Power controls, pumps, and thermal systems contribute to system performance and response times while power is a function of electrode surface area and energy capacity proportionate to electrolyte volumes.

Studies by the University of New South Wales have shown that flow batteries are capable of achieving response times under half a millisecond for a 100 percent load change. This response time is mostly limited by the electrical equipment, suggesting that further developments can improve the performance and use-cases of flow batteries dramatically.

Figure 5. Flow battery at Idaho National Laboratory's Microgrid test bed.
Source: U.S. Department of Energy

Innovations to Watch

Most key players continue to pursue VFRB's, with many moving to bring development and manufacturing of membranes, electrodes, and electrolytes in-house. A majority of innovation centers around reduced costs through use of cheaper materials and higher energy density.

1. **Novel membrane materials:** Nafion has dominated the flow battery market for years, being a key enabler of the technology. However, phasing out Nafion and PSFAs in general are a key research goal due to the toxicity risks associated with Nafion's end-of-life, as the industry aims for alternative materials with lower costs and toxicity with higher ion selectivity. There are many structural motifs used to make ionomers for PEM's, including polyaromatic polymers or partially fluorinated polymers.

2. **Novel electrolytes:** While vanadium has been the industry standard, alternatives like zinc and bromine are becoming more common. Newer alternatives include iron sulfate dissolved in anthraquinone disulfonic acid, with researchers claiming costs of $66/kWh are already possible, primarily due to the abundance of these materials compared to vanadium – though no commercial units are available to validate these claims. One point to note is that many novel electrolyte systems have not been tested to the upper ranges of the lifetime cycles and may struggle to compete with the stability of vanadium redox.

3. **Carbon-based materials for electrodes and bipolar plates:** Several companies are working to develop weldable bipolar plates and electrodes that maintain flexibility while containing high amounts of graphite - raising conductivity and improving system performance. Weldable components can also promote high-throughput stack manufacturing and reduce overall production costs

Figure 6. Zinc-bromine flow batteries in a performance testing lab.
Source: Simon Hackett

KEY DEVELOPERS

Company	Founding Year & Country	Description	Differentiator
Volterion	2016 (Germany)	Bipolar graphite plates and flow battery stacks for grid storage.	Developed a proprietary high-throughput stack manufacturing process enabled by using its bipolar graphite plates. Claims its fully welded stack is compatible with a variety of electrolytes, including vanadium and organic chemistries, and has a life expectancy of 15 to 20 years.
VRB Energy	2016 (Canada)	Vanadium flow battery developer and manufacturer.	Industry leader with 26 patents, including proprietary membrane and bipolar plate material. Stack design features compression-fit components that aid manufacturing and performance. Maintains partnerships with China's electric utility monopoly and **Titanium Resources**, the world's largest vanadium oxide supplier.
Vionx Energy	2014 (U.S.)	Vanadium flow battery developer and manufacturer.	Uses interdigitated flow field architecture licensed from **United Technologies Corporation (UTC)** to reduce pumping losses and increase current density, thereby reducing system size and cost. Maintains 50 patents covering cell and system design, as well as control systems.
UniEnergy Technologies	2012 (U.S.)	Vanadium flow battery developer and manufacturer.	Manufactures modular batteries for various applications and maintains a proprietary balancing scheme to reduce maintenance. Has reached electrolyte energy densities of 30 Wh/L – 71% of the theoretical maximum.
Primus Power	2009 (U.S.)	Zinc-bromine flow battery developer and manufacturer.	Most advanced zinc-bromine system on the market, though it faces tough competition against traditional long-duration Li-ion systems. Maintains 40 patents on cell and stack design, as well as operation. One of 10 companies selected as part of the U.S. ARPA-E ultra-long-duration energy storage grant.

FLOW BATTERIES: HIGH-CAPACITY SCALABLE ENERGY STORAGE

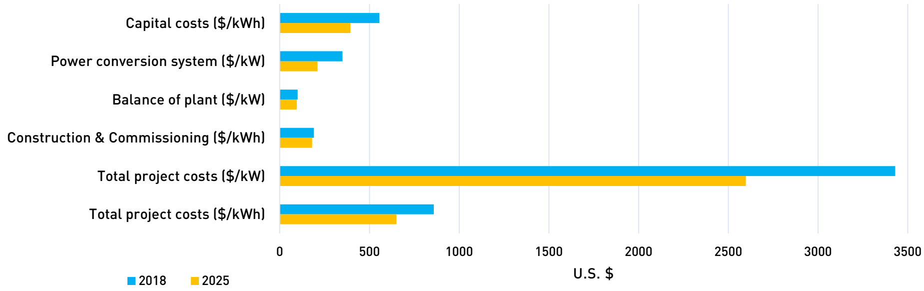

Figure 7.Cost analysis and projections for redox flow battery.
Source: U.S. Department of Energy

Commercial aspects

Flow batteries are deployed in stationary applications or in solar micro-grids like cellphone base stations. They can also offer peak shaving (absorbing demand spikes), backup supply, or power conversion. Load balancing is possible, though limited by low operating current density, leading to high costs. Flow batteries capture no more than 3 percent of the stationary storage market, with lithium-ion accounting for 84 percent of total deployments since 2011 (discounting pumped hydro).

Flow batteries are difficult to commercialize. At a cost of $400/kWh, a 50 MW/200 MWh system would require US$80 million in capital compared to between US$200 and US$300 per kWh, or US$40 to US$60 million, for an equivalent capacity lithium-ion battery. Flow batteries are comparably cheaper for large-scale, long-duration applications.
Only in recent years has the energy landscape required technologies with scales and discharge durations suited to flow batteries: increased renewable power project sizes and higher overall renewable penetration are reaching a tipping point where improved forecasting, flexible generation, and responsive markets are no longer enough to support the energy mix and long-duration storage will become a necessity.
The membrane and electrolyte combined make up around 60 percent of the capital costs of a battery, followed by pumps, electrodes, and control systems.

A 2019 U.S. DoE HydroWires cost analysis projects significant cost reductions for flow batteries in the coming five years. Companies like **VRB Energy** and **UniEnergy** already claim installed costs of $450/kWh to $500/kWh for a 10 MW/40 MWh system, down from ~$700/kWh in 2016. Lack of value chain integration and large-scale production have been key bottlenecks in price reductions and availability needed to scale flow batteries.

Takeaway and Recommendations

Technology developers have struggled with flow battery development, especially in geographies that lack significant renewable generation. Flow battery deployments in 2018 were only 72 MW, compared to 1,629 MW for lithium-ion and 170,000 MW for pumped hydro, with a further 1,670 MW coming from other sources.

For broader adoption, flow battery costs will need to fall, or regulations enabling value stacking for longer-duration storage solutions will need to expand. Without this, lithium-ion is likely to remain the default stationary storage option outside of pumped hydro. Despite their drawbacks, flow batteries are well-positioned to capture a niche portion of growing storage demand, particularly in situations where long-duration discharge, long cycle life, tailored energy and power outputs, or high fire safety are important.

	Metrics	Comments
	Technology value: High	Scalable, long-duration energy storage is crucial to facilitate the energy mix transition over the coming decades. Flow batteries are well suited to fulfilling this task, and are likely to represent a sizeable portion of storage capacity in the grid of the future.
	Momentum: Medium	Momentum of installations has lagged other forms of energy storage, though interest has piqued in recent years and investment is starting to pour in, as the importance of energy storage becomes recognized alongside that of generation assets.
	Maturity: Low-Medium	Scale-up is slow and requires significant upfront capital from customers. High costs have therefore prohibited widespread adoption thus far, particularly as lower-cost Li-ion batteries have continued to drop in price more rapidly.
	Risks: Medium	Systems still need considerable cost reductions to compete with Li-ion. However, the grid storage market and the need for long-duration storage is growing, and flow batteries, well-suited to these markets, are attracting development attention.

LAST MILE DELIVERY

THE BASICS

Logistics companies deliver more than US$300 billion worth of parcels each year – twice as much as in 2015 – through highly complex and capital-intensive operations that ensure fast and efficient delivery. While disrupting these processes is a challenge, large retailers are building their own logistics platforms as they target cost reductions – in particular for last-mile delivery, which can comprise 25 to 40 percent of total delivery costs. New automated solutions such as drones, automated vehicles, and robotics are lowering these costs, especially in rural locations where they are quickly finding use-cases. Despite a number of complex regulatory and engineering challenges – including speed and navigation of complex or unmapped areas – novel last-mile delivery technologies are on track to transform the sector.

Last-mile delivery technologies: disrupting a decades-old model

In more than 100 years, very little has changed about how parcels are actually delivered to your door, outside of the powertrain of the vehicle and the condition of road systems. The complexity of the tasks delivery drivers need to complete means that automation and removing humans from the process is almost impossible today. Not only is navigating roads, particularly in congested urban environments, challenging for delivery drivers, moving the parcel from the vehicle to the mailbox or door of the recipient adds additional complexity. While new modes of transportation like airplanes have innovated in middle-mile transportation, the wide range of address types means that leveraging a road system for last-mile delivery is the only option.

The sheer size of the last-mile delivery market and the fast growth of the e-commerce sector are placing significant strain on logistics companies, which have to meet the expectations of consumers for parcels to be delivered within days of order. This is leading many start-ups to apply technologies developed for other applications to the last-mile market. Similarly, large e-commerce retailers ranging from **Amazon** to **Alibaba** have announced multibillion-dollar investments into their respective supply chains, aimed at promising customers faster deliveries. The primary technologies being developed for last-mile delivery applications include drones, legged and wheeled robots, and autonomous vehicles. These solutions could also potentially allow delivery companies to drop off parcels in a recipient's home or car without them being present, reducing costly failed delivery attempts.

Wheeled robots

Wheeled robots represent one of the last-mile delivery options with fewer barriers to entry. They are easier to develop than autonomous vehicles carrying parcels, because they only need to operate on footpaths and understand few traffic rules. These robots are generally limited to 5-10km/h when operating on footpaths, and usually can also only carry a couple of packages at a time.

Deployments of wheeled robots on college campuses started in 2017 in the US, although human operators still need to be ready to take control remotely at any time. Regulations are generally not an obstacle for this technology due to its slow speeds. Permits are given to companies on a campus-by-campus or city-by-city basis. States in the US have begun establishing regulations, such as speed and weight limits, and rules around how they operate. Washington became the eighth state to create these regulations in April 2019.

Wheeled robots are only likely to be feasible on enclosed areas such as college campuses or geo-fenced city areas with no car traffic, where the incumbent delivery method would be a courier moving by foot or bicycle. The cost benefits of autonomous vehicles make them a better choice in environments with roads.

Figure 1. Wheeled delivery robots.
Source: Milton Keynes

Legged robots

Legged robots can traverse steps and other rugged terrain, as well as bring parcels all the way to a recipient's front door. At this point in time, the technology is the slowest, least mature, and most expensive (usually costing more than US$100,000 for a bipedal robot). Untethered robots have limited range due to power consumption, thus requiring more efficient control. While some tests have been done successfully with legged robots moving parcels, they have proven very difficult to repeat in different environments. As the technology is in early development stages, there are no specific regulations enhancing or blocking its penetration.

Legged robots only solve the last-mile problem in rural or suburban areas with walkways leading to the front door. In cities, people are more likely to have secure drop locations or have the package delivered to where they are. Based on the technology adoption rates of other robotics technologies, the adoption of legged robots for last-mile delivery is unlikely to occur before 2030.

Figure 2. Bipedal robot concept for package delivery.
Source: Golden Sikorka

LAST MILE DELIVERY

Delivery drones

Unmanned aerial vehicles can transport packages faster than any other mode of transport, especially because they can fly in the line of sight of their route. Similarly, these systems have fewer obstacles to avoid compared to ground-based vehicles. However, a limited payload capacity and range have limited the deployment of delivery drones. Regardless, drones are the most technologically mature method of last-mile delivery to date. Recently, developers have been testing use cases such as delivery of medications in remote areas; companies such as **Vayu**, **Unify** and **Nextwing**, for example, are trialing this use case in a UNICEF-enabled test corridor in Malawi. Since the general technology has been around for more than a decade, technology developers now focus on increasing range and power consumption to make the delivery use case more feasible.

A key consideration for air-based delivery services is that civil aviation authorities like the Federal Aviation Administration (FAA) in the US require delivery drone operators to be certified air carriers. The application process can take years, and only a select group of companies are participating in these programs. However, **UPS** recently gained FAA approval to operate a network of commercial drones uninhibited by the restrictions upheld thus far. This will allow UPS to fly drones at night and out of sight of the operator; the approval will also allow the drones to carry cargo over 25kg. Despite this groundbreaking approval, safety concerns as well as air congestion issues are likely to mean long approval periods will continue in the near-term. Regulatory bodies in countries such as Australia are also starting to look at noise limitations for drones.

To date, delivery drones are limited to flying about 10 km from a warehouse, with companies such as **Amazon**, **Wing** – an **Alphabet** subsidiary –, and **JD.com** – in partnership with drone developer **Rakuten Drone** – being notable examples conducting pilots in urban areas. Considering their range, only populations living within a 10km radius would be accessible by drones. Many warehouses are located in urban areas, which would not be feasible for drones due to noise and congestion concerns. Nevertheless, companies such as **Matternet** – in cooperation with **UPS Flight Forward** – and **Wingcopter** are working on hybrid fixed-wing/multirotor designs that promise to increase the delivery range to 100km. This can not only expand the range of delivery in urban areas, but also enable the use case of parcel deliveries in remote areas more difficult to access by roads.

Figure 3. Delivery drone with package.
Source: PhoelixDE

Autonomous vehicle lockers

Autonomous vehicle (AV) lockers consist of storage compartments within the vehicle that can be unlocked by the recipient. They can carry many more parcels at a given time than any other automated technology, providing potentially the largest overall delivery throughput. Parcel recipients do need to be home to accept the parcel as AVs only travel on roads; this technology would thus require a software layer communicating more accurate delivery times to recipients. The basic technology stack will be similar to AVs used in ride-hailing applications, with only the interior of the vehicle changing. Developers such as **Pony.ai**, in partnership with e-commerce company **Yamibuy**, are testing this technology to deliver groceries in the US. Though AV technology has seen an increasing number of pilots from companies like **Waymo**, scaling to more complex geographies and urban environments will likely take years.

Figure 4. Autonomous vehicle locker for last-mile delivery.
Source: Focusone Design

An increasing number of US states allow AVs on public roads (usually requiring a human safety driver), and other countries are following the US's lead. AV companies generally require a waiver to operate vehicles without a safety driver.

LAST MILE DELIVERY

Autonomous vehicles benefit from the fact that they are feasible to use in both urban and rural environments. With larger payload capacities than any of the other competing technologies, they can carry virtually any size parcel and many parcels at a time. Furthermore, new concepts combining AVs with another last-mile delivery technology have started to emerge. These systems use AVs as a mobile "hive" that deploys either drones or legged robots, effectively extending the delivery range of the latter systems, while reducing or eliminating the need for AVs to interact with the recipient of a parcel.

Challenges and prospects

Automating last-mile solutions is challenging, as it requires dexterity, speed, and navigating a highly complex and likely unmapped path to a recipient's door. Range is also challenging, with technologies like drones being limited to deliveries within a roughly 10km radius of a warehouse. Regulations will also play a key role boosting or limiting the deployments of last-mile delivery technologies in different geographies. Drones and wheeled robots, while closer to real deployments, are limited in the long term due to the areas they will be restricted to. Legged robots are not anticipated to begin deployments until after 2030. Autonomous vehicle lockers are poised to deliver more than 20 billion parcels by 2030 as they can operate in most addresses.

Autonomous vehicles operating in a "hive" model will be mostly limited to small parcel deliveries in rural locations. Standalone AVs serving remote communities will be ready sooner, as they won't have to navigate beyond main roads. Parcel delivery will remain mostly manual in 2030, primarily because few business recipients are expected to use automated delivery. Today, business recipients account for almost half of all parcel deliveries and are among the most profitable routes due to the high number of parcels each person can deliver at once. There is less cost pressure to automate when receiving many parcels at a single address.

Although large logistics companies and retailers will likely implement the vast majority of new last-mile delivery technologies, start-ups play a crucial role in developing the technologies. However, the emergence of new business models is required for start-ups in the space to ensure profitability in a highly competitive space. Companies such as **ZhenRobotics**, for instance, develop a range of robotics outside of just last-mile delivery, while **Savioke** is focusing on specific use cases like hospitals and hotels. Other start-ups creating technology for last-mile delivery are positioning themselves as "robot-as-a-service"-type businesses.

Because logistics companies have little experience in robotics, it is likely that they will outsource the last mile to these technology companies, which, in addition to the hardware, are building fleet management and route optimization software. While large logistics companies with internal technology groups (e.g., **Amazon**, **JD.com**) will be less likely to engage in this service model, small and midsize companies will. Though some logistics companies and retailers will acquire promising technology start-ups after an initial period of paying for services, some start-ups will continue to operate as delivery agents able to build larger fleets by combining deliveries from several companies at once.

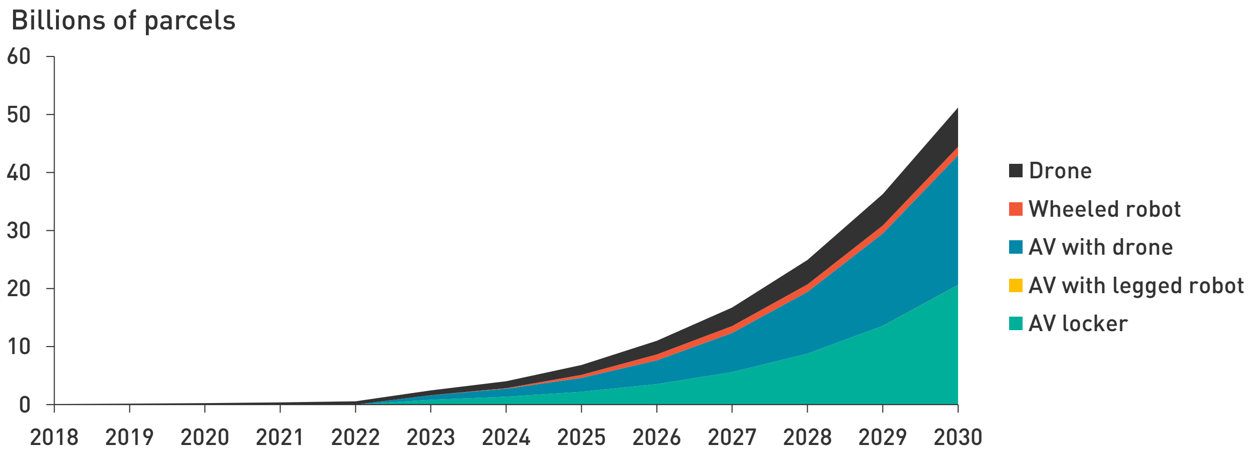

Figure 5. Projected parcel delivery volumes using automation technologies
Source: Lux Research

NEWS UPDATES

Bloom Energy expands into electrolysis for green hydrogen production

Bloom Energy is moving to adapt its solid oxide fuel cell (SOFC) technology to solid oxide electrolysis (SOEC), in order to produce hydrogen from water – joining **Sunfire** as the only other noteworthy player in the space. SOEC systems exhibit long-term stability, low emissions and costs, and high efficiencies by converting steam - and not water - directly to hydrogen. This mode of operation at high temperatures enables electrical-to-hydrogen conversion efficiencies of approximately 90%.. However, operating temperatures of 500° C to 850° C create issues of long start-up and break-in times, potential chemical instability, and thermal expansion.

Reaction Engines tests ammonia for carbon-free aviation

Reaction Engines is a UK-based aerospace company that develops cutting-edge hypersonic engines and heat exchanger technologies. The company has completed a proof of concept study with the UK's Science and Technology Facilities Council (SFTC) to assess the viability of using their thermal management technology with SFTC's catalysts to enable green aviation based on ammonia fuel. The system was proven to require only minor adjustments to aircraft and engine design by using cooled, pressurized liquid ammonia - helping to overcome challenges of ammonias lower energy density compared to kerosene fuels, though significant safety challenges remain.

100 MW green ammonia plant to launch in Spain in 2021

Iberdrola and fertilizer producer **Fertiberia** are set to launch a US$175 million, 100 MW green ammonia project in Puertollano, Spain next year. The plant will use photovoltaics to produce green hydrogen that **Fertiberia** will combine with nitrogen from its fertilizer operations to produce green ammonia, with the company predicting a 10 percent reduction in natural gas consumption. Although financial incentives are lacking for low-carbon fertilizers, decarbonization regulations and corporate emission targets may drive similar collaborative projects.

Erebus 96 MW floating wind farm in Wales passes regulatory hurdle

Blue Gem Wind, the joint venture between **Total** and **Simply Blue Energy**, has obtained leasing rights from the UK Crown Estate, taking another step towards realizing its demonstration project and **Total**'s first major move into wind. The approval allows the company to progress with environmental assessments and surveys, secure connection to the grid, and apply for final planning permission. The leasing deal comes after several recently granted seabed rights from the Crown Estate, including a 106-square kilometre extension to the Gwynt y Mor wind farm that could add 576 MW of capacity.

NEWS UPDATES

Iberdrola set to close coal plant in Spain

Following a string of fossil fuel plant closures – totalling 8.5 GW since 2001 – Iberdrola has announced its intention to close the 355 MW Lada coal-fired power station. As part of the company's commitment to the EU Commission's 'just transition' programme, plant workers have the option to undergo retraining to operate wind farms that will eventually be installed in the region, mirroring the German coal exit-strategy that emphasized worker retention and retraining.

Toshiba installs commercial-scale fuel cell combined heat and power system

Toshiba Energy Systems & Solutions has installed a 3.5 kW proton exchange membrane (PEM) hydrogen fuel cell system to provide power and hot water at its Michinoeki-Namie facility, with green hydrogen sourced from the company's nearby 10 MW solar-powered Fukushima Hydrogen Energy Research Field. The move highlights the critical nature of developing and securing hydrogen supply chains when using hydrogen fuel cell systems to provide power and heat.

Floating wind farm WindFloat Atlantic begins operations

WindFloat Atlantic, jointly developed by **Portuguese EDP Renewables**, **Engie**, **Repsol**, and **Principle Power**, is the world's first semi-submersible floating wind farm at 25 MW. Semi-submersible turbines stand atop floating platforms a few meters high that are moored with flexible anchors to the ocean floor. This allows for onshore assembly and towing to installation site, as well as easier maintenance than alternative designs. **Tokyo Gas**'s investment into **Principle Power** was a key driver of the project, as both companies look to develop a WindFloat supply chain.

CRI completes demonstration of methanol energy storage system

Carbon Recycling International (CRI) has completed a 1 tonne per day demonstration of its methanol synthesis process at a facility in Niederaussem, Germany – co-locating with **RWE**'s thermal power plant for CO_2 sourcing. The process, that couples waste CO_2 with water electrolysis-derived H_2 over a solid catalyst, proved the ability of **CRI**'s reactor to respond to fluctuations in hydrogen availability and methanol synthesis without affecting conversion efficiency. The project is a key milestone in the deployment of the company's technology for chemical energy storage purposes.

World's largest battery storage complex comes online

The 250 MW Gateway Energy Storage project has joined the grid to help minimize the rolling blackouts that state operator California ISO has been forced to introduce during recent heat waves. The project, operated by **LS Power** using **LG Chem** Lithium-ion cells, is part of a series of planned installations by **LS Power**, including 316 MW set for operation in New York in 2021, and two other Californian installations totaling 325 MW. The installation is a clear sign of the role that energy storage has to play in overcoming energy challenges imposed by both global warming and the energy mix transition.

TECHNOLOGY BREAKTHROUGHS

Transparent solar panels for windows hit record 8 percent efficiency

A team led by researchers at the University of Michigan has set an 8.1 percent efficiency record for color-neutral, transparent solar cells. The team utilized a carbon-based design, as opposed to conventional silicon, overcoming challenges in ensuring both adequate sunlight absorption and high voltage and current, to achieve a 43.3 percent transparency when using an indium-tin oxide electrode. Swapping this out for a silver electrode managed to increase efficiency to 10.8 percent and transparency to 45.8 percent, though the resulting green tint would likely hinder the panels adoption in most residential and commercial applications. Both versions can be manufactured at scale, using less toxic materials than existing transparent solar cells. Optical coatings were also developed, helping to boost both power generation from infrared light and transparency in the visible range, properties that usually compete. The combination of economically viable efficiency ratings and high transparency is moving the technology closer to enabling power-generating windows for large-scale buildings like skyscrapers.

BATTERIES USED AS VIRTUAL POWER LINES FOR MORE RENEWABLES

Virtual power line concept

The increasing share of wind and solar photovoltaic (PV) electricity in power systems requires efficient management – and, in some occasions, the reinforcement of transmission and distribution networks - to prevent congestion. As an alternative to expensive upgrades to the infrastructure needed for the grid-integration of variable renewable energy sources, like solar and wind, non-wire alternatives, also called virtual power lines are being rolled out in several parts of the world.

To support the existing network, while enhancing the performance and reliability of the power system, virtual power lines include batteries connected at least at two locations in the grid. One battery at the supply-side, close to the renewable generation source, stores surplus electricity production that cannot be transmitted to the demand side due to grid congestions (and which would otherwise be curtailed). Another battery is placed at the demand area, which would be charged whenever transmission capacity is available, and demand is low.

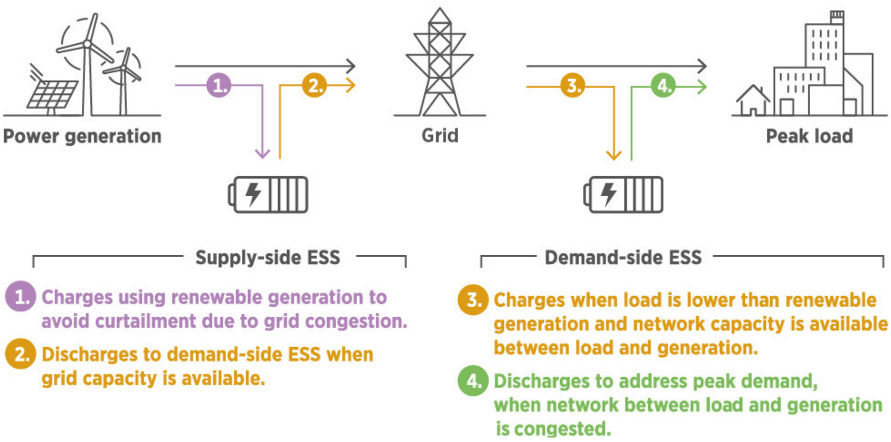

Figure 1: Schematic representation of the virtual power line concept
Source: IRENA

Benefits of virtual power lines

Seen differently, virtual power lines are one specific application of energy storage systems (ESS). Used as virtual power lines, utility-scale batteries provide several potential benefits, such as adding electricity capacity to the grid much faster and, in some cases, at lower costs comparing to conventional infrastructure reinforcement or expansion (see Table 1). In addition to congestion management, virtual power lines are also well-suited to providing a range of ancillary services. Batteries can provide fast frequency response, which could replace peaking gas power plants. They can also offer system inertia, traditionally provided by coal-fired plants, for which synchronous condensers have become the main requirement, and flexible ramping.

However, the regulatory framework dictates whether batteries used as virtual power lines can also participate in the wholesale and ancillary service markets, where such markets exist.

Network upgrade challenges	Benefits of VPLs
Lengthy (multi-year) planning, permitting and development process	Storage systems can be designed and built, and be operational, in several months to defer transmission upgrades or at least provide resilience for the network through the lengthy development process.
Uncertain load growth rates and demand patterns	VPLs with the ESSs can be deployed in small modular capacity increments, avoiding oversizing and stranded assets.
Single function of transmission capacity	When not needed for transmission and distribution network deferral, ESSs can have multiple uses such as generating revenues and reducing grid operation costs by providing frequency regulation, voltage support, spinning reserves and other services, provided regulations allow them to provide such services.
Local community opposition	The ESSs could have a smaller impact on nearby property values compared to transmission lines, as the ESS are often installed at substations or existing grid facilities.

Table 1: Network upgrade challenges, compared to benefits of virtual power lines
Source: IRENA

To unlock innovative business models that make virtual power lines more economically attractive, energy storage systems should be permitted to provide a range of services, including storage to reduce congestion, which would help to defer network investment, as well as ancillary and balancing services, such as frequency and voltage regulation. From a cost-effectiveness point of view, the optimal use of the battery itself should also consider the number of charges and discharges per day and the life span of the battery to provide such services. Allowing the stacking of multiple revenues is key to improving the business case for storage and maximising its social welfare.

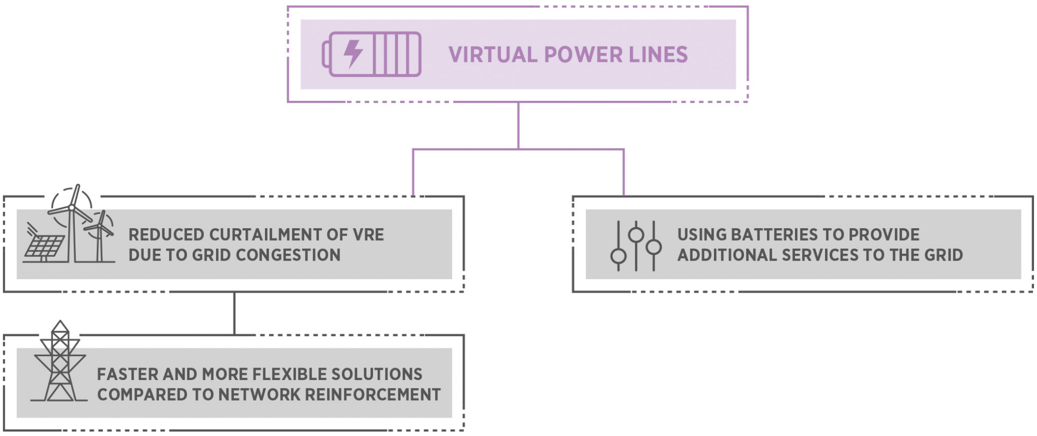

Figure 2: Contribution of virtual power lines to integrate variable renewable energy
Source: IRENA

Progress and implementation

Virtual power lines are starting to attract interest in several countries. There are already close to 3 gigawatts (GW) of batteries planned to be used as virtual power lines in different geographies, with projects ranging from a few megawatts (MW) to GWs. For example, France's transmission system operator (TSO), **RTE**, is implementing its first 40 MW pilot project, named RINGO, with the goal of increasing grid integration of renewable energy and optimising electricity currents on its network. A German grid development plan produced by all four TSOs in the country, has proposed 1.3 GW of energy storage to ensure grid stability and lower network costs. In January 2019, the **Andhra Pradesh Transmission Company,** a publicly owned utility in India, proposed between 250 MW and 500 MW of energy storage to add capacity to its transmission network with an innovative cost recovery mechanism that includes allocating costs between renewable developers and distribution companies that have an obligation to serve load.

In the United States (US), **Pacific Gas & Electric** selected a 10 MW energy storage project as part of a portfolio of transmission solutions during its regional transmission planning process, the first such project chosen to provide congestion relief in US markets. In addition, in 2018 the **PJM Interconnection** market in the US received proposals for multiple battery-based storage projects between 25-50 MW to help relieve network congestion issues. Similarly, in Australia, projects using battery-based storage as virtual transmission are being considered alongside traditional poles and wires to add capacity on key interstate transmission lines.

Virtual power lines show that, if innovation in technology is accompanied by innovation in regulation, business models and system operation, energy storage systems can be deployed at scale and in a cost-effective manner to support the integration of very high shares of solar PV and wind energy in global power systems. IRENA's report "Innovation Landscape for a renewable powered future" identifies 30 key innovations that can reduce the cost of integrating large shares of renewables in today's power systems, with virtual power lines and utility-scale batteries being among them.

Description	Key facts
Countries where VPL projects are being piloted	Australia, France, Germany, India, Italy, United States
Storage capacity of VPL projects currently being considered or constructed (as of 2019)	**Globally:** 3 GW **US:** 62.5–87.5 MW (3 projects) **France:** 40 MW **India:** 250–500 MW **Chile:** 400 MW **Germany:** 1 300 MW **Australia:** > 1 000 MW **Italy:** 35 MW
Expected growth in battery storage for transmission and distribution investment deferral	~ 14 300 MW by 2026

Table 2: Progress made so far by virtual power lines
Source: IRENA

IRENA
International Renewable Energy Agency

TOPICS FOR NEXT EDITION

Brine desalination and zero liquid discharge

Desalination globally produces over 100 billion liters of potable water per day, with a similar volume of concentrated brine that requires disposal. Generally, brine is diluted – if regulated – and pumped out to sea. Brine's higher density than seawater causes it to fall to the sea floor around outlets and create a salty layer that can raise local pH and temperature conditions, creating hostile environments for marine life. Reducing the percentage of brine produced via desalination is a key challenge for developers to both increase water yields and profit margins. A number of technologies are driving the journey to zero liquid discharge, in which brine can be distilled to leave only the total dissolved solids and potable water, removing the need for brine discharging altogether.

Floating solar

In regions affected by land constraints, the business case for solar deployments becomes far less clear than in regions with abundant space. Offshore wind farms can minimize the need for conventional solar modules on the ground, yet only a limited number of regions fit this profile, with most likely to rely on solar to meet their demand needs and decarbonization goals. Floating photovoltaics (FPV), or floating solar, are one alternate solution that can enable vast renewable generation, while saving precious land resources for higher value uses, such as housing, agriculture, and industry. FPV involves photovoltaic modules mounted on floating platforms for deployment on various bodies of water. These are often inland, such as hydroelectric dams, lakes, and reservoirs, though some marine-based variants exist. Despite there being only 3 GW of installed FPV capacity globally, the technology is a promising facilitator of renewable energy generation for highly-populous nations, with significant adoption expected in the long term, as capital expenses decline and land acquisition costs continue to trend upward.

Impacts of renewables penetration

Efforts to increase renewable power generation have increased considerably since the early 2000s, driven by advances, falling costs of wind and solar, and increasing regulatory and societal pressure to reduce carbon emissions. Yet grids with high penetration of intermittent renewable power can struggle to align supply and demand, and maintain power quality. This results in more frequent blackouts, and the ongoing and erratic need for costly and carbon-emitting fossil fuel peaker plants to meet demand, working against the very goals of decarbonization. With an accelerating penetration of renewable power, several existing and conceptual energy storage and generation technologies can help minimize the impact of the diverging supply and demand realities. To understand the impacts of high renewable penetration on an ill-equipped grid, solar-leading regions such as California and Hawaii make for ideal case studies for energy stakeholders to understand the technical and market needs to increase renewables share without forfeiting functionality.

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