Energy Storage:

Opportunities & Challenges

Prepared by AXIS in collaboration with Renewables Consulting Group

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I. ENERGY STORAGE: OPPORTUNITIES & CHALLENGES

Introduction

This report has been commissioned by AXIS to provide insights into energy storage with a bias to battery storage, technologies and challenges for those wishing to take full advantage of the opportunities these technologies bring.

Electricity is the world's fastest-growing form of energy consumption[1]. Yet, current global trends in electricity supply and use are considered unsustainable from an economic and environmental perspective. Consequently, the future energy landscape is changing. Decarbonisation[2] and modernisation of the electricity industry, towards smarter, more disaggregated and more decentralised energy systems, are now a priority. Battery storage is at the heart of this transition.

Whilst pumped hydro-electric storage remains the incumbent worldwide storage technology (with a global capacity of around 99%[3]), the market share in the remaining non-hydro-electric technologies is expected to grow exponentially in the coming decade. A key driver has been the need to integrate intermittent[4] (or sometimes referred to as 'variable') renewable power generation in countries where the proportion of renewables is high (e.g. Australia, Germany, Denmark, China and parts of the US).

Battery storage (in particular electrochemical storage systems at utility scale) has been identified as a critical 'step-change' in the future penetration of renewables and its dispatch. Even though, the battery industry is in a period of transition, significant advances in technology and changes in their economics has brought a wide range of storage applications to the market. In this optimistic space, the conditions are becoming more favourable for both purchasers and suppliers. Suppliers, for example, are now seeking commercial opportunities and looking to establish themselves as global market leaders[5].

The need for battery storage technologies is clear. Moreover, the evidence indicates this need will continue to grow. But as in any rapidly maturing market, where technology types are evolving at different rates of commercial readiness, deployment is complex and comes at a price. Fortunately, in the right situation, batteries can provide services that improve and secure revenue for a project.

Different energy storage systems grouped by technology

STORAGE SYSTEMS	
MECHANICAL	Pumped hydro & flywheel
THERMODYNAMIC	Compressed air, cryogenic storage & heat engines
ELECTRICAL	Capacitors & superconducting magnetic energy storage
CHEMICAL	Hydrogen / organic cycle, fuel cells, electrolyser & ice
THERMAL	Pumped heat / heat engines, molten salt, ice & ceramics
ELECTROMECHANICAL	Batteries: lead acid, nickel cadmium, high temperatures, flow, lithium & metal-air

II. APPLICATIONS, BENEFITS & SCOPE FOR USING ENERGY STORAGE

Why does the electricity supply system need storage?

Electricity is a continuous service and ensuring power grids can maintain a robust and resilient delivery system, without disruption, requires supply and demand to be precisely balanced at all times[6]. This is challenging for the network operator as demand is constantly changing, although it does follow predictable patterns. However, forecasting these patterns is not a precise science and failure to maintain the balance could result in consumption needs being compromised or result in costly blackouts.

To maintain a continuous service, generators are called upon at the request of the grid operator to make constant adjustments to supply, either upwards or downwards in response to predefined time frames and ramping rates. Whilst supply is conventionally provided by coal, gas or pumped hydro-electric resources, there has been a shift towards battery storage to provide these frequency response services at very short notice.

Other applications include; alleviating saturation and electrical problems[8] (as storage facilities are much easier to install than transmission lines[9]), and 'fringe-of-grid' energy supply (as an alternative to network or micro-grids). In this application, storage is used for maintaining high quality and reliable electricity supply to remote and costly load centres at the fringes of the power network[10].

However, power grids that have not been designed to meet intermittent renewable integration (i.e. do not have adequate compensating measures), are often unable to provide satisfactory performance when power from these sources exceeds 20-25% of the whole generated power[11 & 12]. In this case, compensation can be provided by battery storage[12]. The increased penetration of renewables is making storage applications more critical and creates opportunities such as "intermittent balancing" to avoid curtailment[13]

Electricity storage has two primary functions:

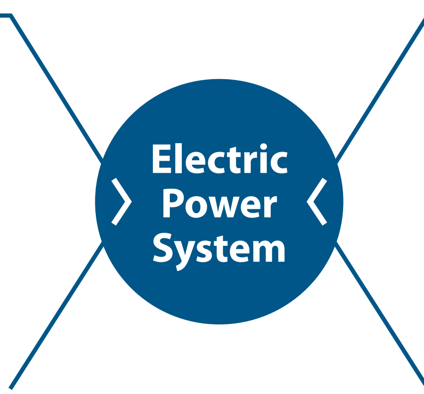
- Levelling the demand curve or load levelling: Storing power during periods of light loading on the system and delivering it during periods of high demand. For the power grid operator, this reduces the load on less economic peak-generating facilities and provides economic benefits by deferring major capital investments to grid improvements[7].
- Ancillary services: A suite of specialist services that allows the power grid operator to ensure a continuous service of electricity.

Supply and demand challenges facing electricity supply systems

Globally, electricity supply systems are facing increasing supply and demand issues, which in part can be addressed by energy storage.

Supply

Penetration of renewables
Hedging energy prices
Distributed assets and resources
Constrained networks
Resilient power supplies
Aging infrastructure



Demand

Demand increase from digital
Increasing peak demand
Higher summer peak
Incorporating electric vehicles
Smart grids
Fuel saving

Why are revenue streams from energy storage highly variable?

The business case for battery storage is very complex and opportunities for revenue streams are highly variable. This is because in many countries market conditions and regulatory frameworks, that promote their application, are also variable. Moreover, further complexity is introduced as commercial arrangements also vary depending on where in the value chain storage is deployed and the type of technology used (Exhibit 1).

Other opportunities to receive mutually inter-dependent and multiple income streams (sometimes referred to as 'benefits-stacking'[14]) include, time-shifting of electricity production, overcoming network constraints, peak-lopping / shaving[15] and ancillary services. These are critical offerings in the value proposition for many battery storage technologies.

However, it is vital that developers and other parties interested in battery storage understand where the income streams are likely to come from. Ancillary services, for example, provide the highest financial value for the Independent Power Producer (IPP) and so many storage installations are founded on this business model. Although not all markets are favourable to battery storage providing these services. Equally, the opportunity to use batteries for time-shifting has its technical merits, but the reality is that most power grids already have an effective control over balancing generation to match demand using cheaper alternatives (e.g. use of diesel standby).

Exhibit 1: Commercial summary of users of energy storage across the electricity supply chain

SERVICE TYPE	SERVICE	KEY POINTS
GRID, TRANSMISSION AND DISTRIBUTION SUPPORT	Frequency Reponse	Monthly to multi-year contracts. Highest value. Market competition between providers of demand-side response, traditional generation stations and energy storage systems. Typically entails waiting in stand-by until a disturbance on the grid at which point power must be delivered. Frequency response is either dynamic or static.
	Short Term Reserve	Seasonal to multi-year contracts. Competition as above. Entails waiting in stand-by (warning of minutes to hours).
	Reactive Power	Annual or seasonal contracts. Low value service available in certain locations only.
	Capacity / Peak Demand Reduction	Not commonly available via market; occasional tender or auction opportunities (there is a Capacity Market in the UK). Location-specific.
RENEWABLE ENERGY SUPPORT	Managing Renewable Energy Constraints	Not commonly available via market; occasional tender opportunities. Can be location-specific if supporting transmission & distribution networks. Might require co-location with a renewable generator.
MARKET	Energy trading	Accessible via energy markets. Delivery typically scheduled. Low annual average earnings unless grid has capacity shortage. Difficult to forecast.
	Portfolio Balancing	Energy portfolios comprising generation and demand may be 'short' or 'long' and exposed to a balancing cost. Flexible resources are of value in reducing the imbalance. Typically, low value due to other options being available.
CUSTOMER-SITE SUPPORT	Peak Demand Reduction	Industrial customer is billed according to the maximum demand, which can be reduced by generating from energy storage. Calculated annually. Storage must be co-located at the demand site and dispatched at peak demand.
	Energy trading	Difference between peak and off-peak prices. If storage operates to discharge during peak times and to charge during off-peak times, revenue possible. Storage must be co-located at the site behind the meter. A separate contract is not required as the saving is made by reducing the energy consumption, but a contract may be needed with site owner.
	Energy Independence	Similar to above, storage can be operated to allow sites to operate independently of electricity networks. Desirable for green credentials or providing a more-secure and stable electricity supply, where grid is poor quality or interruptible. No contracts required, but may be needed with site owner. Typically, low-value.

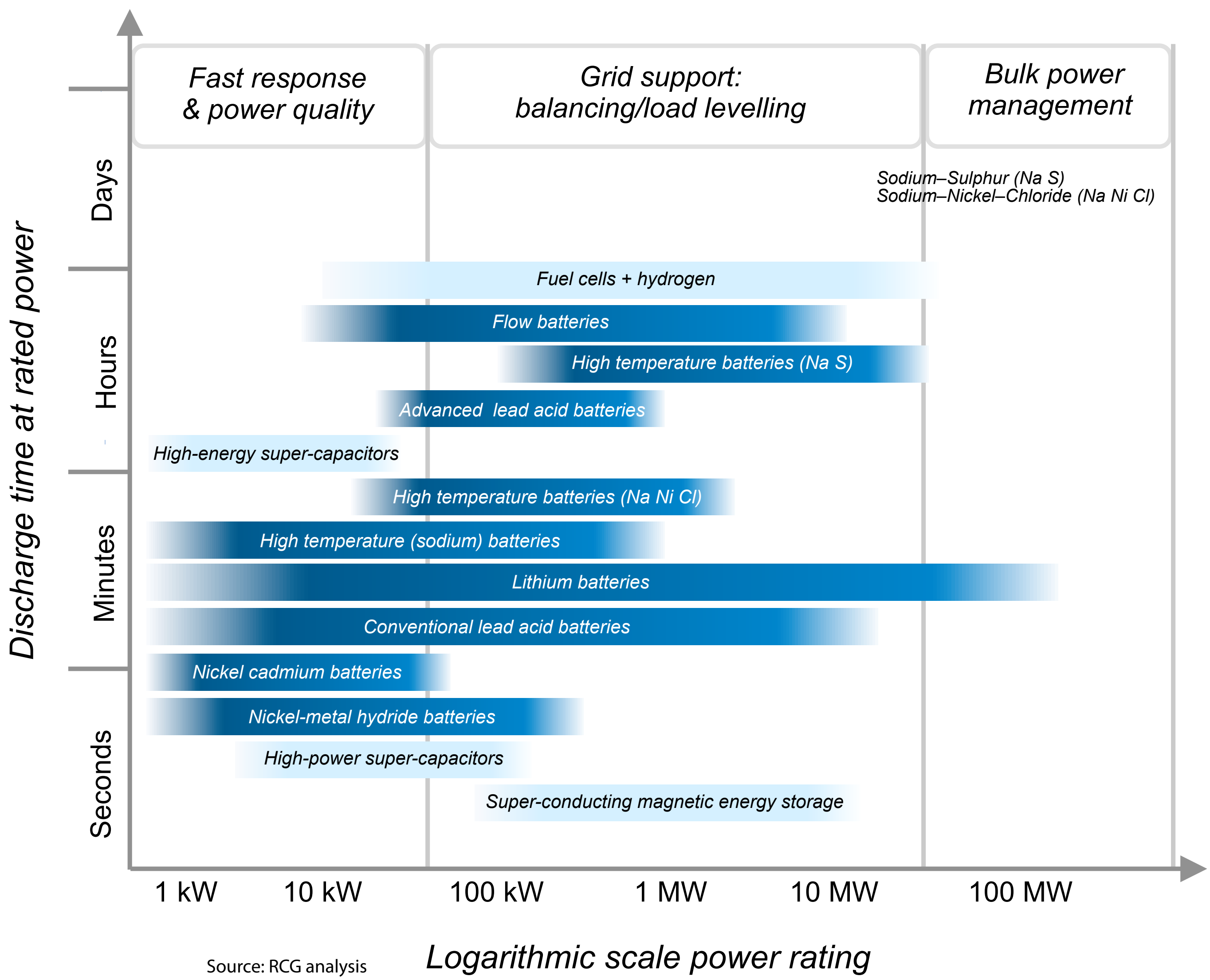
III. MAPPING STORAGE TECHNOLOGIES TO APPLICATIONS

How are battery technologies applied across the value chain?

The versatility of battery storage can ensure both short-term and long-term services are efficiently provided through a wide range of applications. However, the application of battery storage technology depends on its performance characteristics, namely capacity, speed of response (discharge time) and physical size of a unit (measured in power rating) (Exhibit 2). Other factors include lifetime, environmental acceptability and safety, and efficiency (Exhibit 3).

These characteristics determine what services they provide and where on the value chain they should be deployed. Lithium batteries, for example, provide the widest range of applications compared to other storage technologies.

Exhibit 2: Battery types, by capacity, discharge times and application



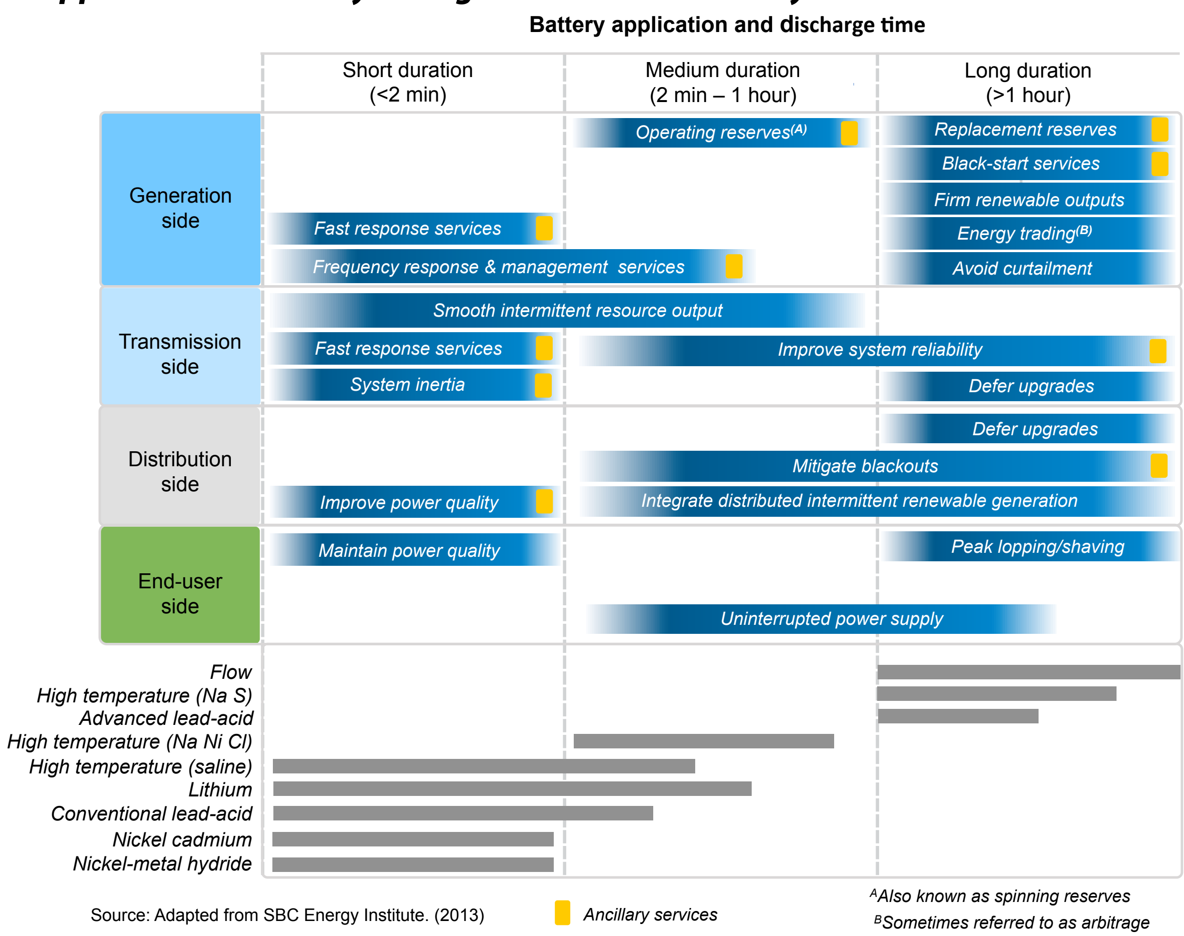
Source: RCG analysis

Exhibit 3: Summary key parameters for different battery storage technologies and siting considerations

TECHNOLOGY TYPE	POWER RATING	ENERGY STORAGE CAPACITY	SPEED OF RESPONSE	LIFETIME	ENVIRONMENTAL ACCEPTABILITY AND SITING REQUIREMENT	EFFICIENCY
LEAD ACID BATTERIES	Small to large scale	Medium (up to 3h)	High	<15 years ~ 2000	Acceptable. Battery electrolyte containment important	85-100%
NICKEL CADMIUM/ METAL BATTERIES	Small to large scale	Medium (up to 3h)	High	<15 years	Restrictions in place on use of Cd. Battery electrolyte containment important	70-85%
HIGH-TEMPERATURE BATTERIES	Medium to large scale	Medium (up to 6h)	High	~ 2500 full cycles	Good environmental. Suitable for industrial areas	70-85%
FLOW BATTERIES	Small to large scale	High	High	Varies. Can be ~ 15 years	Battery electrolyte containment important	70-85%
LITHIUM BATTERIES	Small to large scale	Low	High	~ 10 years	Acceptable	85-100%

Power to the electricity supply system is usually required at short notice (e.g. seconds to just a few minutes and hours) (Exhibit 4). Battery storage technologies are ideally suited to providing power at short notice. This feature is critical as supply to the power grid on these terms is considered to be of high revenue value.

Exhibit 4: Application of battery storage across the electricity value chain



The arguments for battery storage are very persuasive. They offer important opportunities due to their modularity, relative simplicity, speed of installation, low maintenance, high reliability, and (more recently) a steep downward trend in their price trajectory.

There are now a wider range of battery storage technologies on the market with different applications (Exhibit 5).

Exhibit 5: Summary of battery storage technologies and their application

BATTERY TECHNOLOGY	APPLICATION
LEAD ACID BATTERIES	• Lead acid batteries are still the most popular and widely available throughout the world (e.g. flooded cells and gel type systems). • From small installations in domestic or remote areas to larger systems (>10MW) as in telephone exchanges or data centers where they have been used for standby power. • Over 95% of battery can be recycled.
NICKEL CADMIUM/ METAL BATTERIES	• Nickel cadmium / metal batteries are used in applications where long lifetime and durability is required (e.g. aviation, rail, telecoms, engine starting and standby power. • Environmental legislation on pollution from toxic heavy metals is inhibiting use of nickel cadmium batteries and special care needed for disposal.
HIGH-TEMPERATURE BATTERIES	• Sodium sulphur batteries are one of the most widespread advanced battery systems in commercial deployment. • They are very efficient and with good reliability. • Ideally suited to larger scale applications (>5 MW). • Sodium nickel chloride batteries share some characteristics with sodium sulphur batteries, but have different operational parameters. • Originally intended for vehicle applications, but are now used in a small number of stationary storage applications.
FLOW BATTERIES	• Flow batteries may be configured as packaged systems, containerized or large-scale. • Electrolytes can be chosen from a wide selection of electrolytic couples depending on cost, availability and performance. • Two popular electrochemical couples are zinc bromine and vanadium / vanadium. • Zinc bromine battery systems tend to be either packaged or containerized. • Vanadium / vanadium are available in all configurations.
LITHIUM BATTERIES	• Lithium batteries are light weight and used for large scale applications on power networks and configured for low cost of maintenance and high lifetime. • Lithium is highly reactive to water and must be used with non-aqueous electrolytes. • Cells can be prismatic, cylindrical or of the pouch type to suit the application. • Performance can be optimized to match the power requirements, weight and volume.

IV. BARRIERS AND RISKS TO BATTERY STORAGE DEPLOYMENT

What are the barriers to deploying battery storage?

The advancement of battery storage systems is concentrated in selected markets and regions across developed economies, and widespread deployment still faces a number of barriers (Exhibit 6).

Exhibit 6: Summary of main barriers to battery deployment

BARRIER	DESCRIPTION
SUPPORT MECHANISMS AND POLICY DRIVERS	Policy and regulatory changes are needed to support deployment (e.g. supporting storage demonstrator projects); to support integration of variable renewables to meet country renewable targets, and create an equal level playing field or cross border trading of electricity storage, provide clear rules and responsibilities concerning technical and financial conditions. Yet, few countries have implemented the necessary regulatory changes to facilitate market growth (exceptions: USA, Germany, Australia, UK, Denmark). Tariff structures, competition in metering and incentives for demand management will allow storage to become more competitive with other fuels supporting load curtailment, intelligent control systems and embedded generation. It must address barriers preventing integration of storage into markets.
REGULATION & STANDARDS	Industrial standards for grid storage are in their infancy. Industry acceptance could reduce uncertainty surrounding how storage technology is used and monetized at scale. Ultimately, the experience of real-world application will provide confidence and expand installed storage capacity.
COST COMPETITIVE ENERGY	Generally, mass deployment of battery technologies is still too costly. Significant changes to relevant regulatory frameworks (to incentivize development & deployment), improvements in technology and manufacturing, commercialization, and a greater deployment history will be needed.
GRID RESILIENCY & RELIABILITY	Energy storage should be available to industry and regulators as an effective option to resolve issues of grid resiliency and reliability. Validation of the safety, reliability, and performance of storage is essential for user confidence.
INDUSTRY ACCEPTANCE	Energy storage should be a well-accepted contributor to realization of smart-grid benefits; specifically enabling confident deployment and optimal utilization of demand-side assets. Industry acceptance requires confidence in storage and needs to deliver as promised. The industry is still in its infancy and must address questions from developers, funders, and interested parties.

What are the risks associated with battery storage deployment?

Technical risks

The risk profile of a battery is technology specific (Exhibit 7). Many battery technologies are still under development and so have fundamentally different profiles compared to more mature technologies, where the risks have already been identified by the insurance industry and appropriate mitigation proven.

Battery technologies are also inherently hazardous as they utilize materials that have the potential to react violently with each other. Lithium batteries, for example, are non-hazards in most contexts, but have properties that can develop hazardous conditions (e.g. voltage, arc-flash, blast, fire and vented gas combustibility and toxicity)[17]. The major concern is the risk of fire or an explosion and consequential thermal runaway. Recent experience of lithium batteries suggests that mishandling the battery or an external event is a contributing factor (e.g. recently cases in aviation).

Battery systems have narrow operating temperatures. Lithium batteries, for example, need to be maintained within a temperature range of +5°C to +25°C (usually controlled by air conditioning). Failure in the air conditioning system could result in the battery temperature rising outside its safe operational limits and causing serious damage.

Safe operation of a battery is only assured within certain environmental conditions (e.g. temperature, humidity, condensation) and operational conditions (e.g. overcharge or undercharge) are controlled and maintained using a Battery Management System (BMS). A BMS is also one way to mitigate risks.

The weight and size of the battery is also an important consideration for ground loadings, the construction and installation of racks, and their accessibility. Dedicated craneage, fork lift trucks or other equipment may be needed.

Each battery technology should be assessed on its own merits as they often have fundamentally different responses to physical damage (e.g. shocks, drops and collisions). Physical damage could create electrical short-circuits or other battery malfunction, which could (worst-case) result in total loss of battery module. Damage to the battery casing could cause a leak of electrolytes and potentially the secondary effects from the flows of acids or other corrosive materials.

Exhibit 7: Risk profile card: Technical asssesment of a battery storage project

COMPONENT	SUB-ELEMENT	RISK	POTENTIAL IMPACT	QUESTIONS TO ASK	RATING
ELECTRICAL CONNECTION	Switchgear	• Explosion	Physical damage, outage	• Substation design codes	Low risk (yellow)
POWER CONVERSION SYSTEM	Transformer	• Explosion • Noise	• Physical damage, outage, complaints	• Location • Bunding • Shielding	Very low risk (green)
	Controller	• Data • Communications failure	• Inability to trade	• Risk increases if all one supplier • Importance can be neglected by new entrants • Experience	Very low risk (green)
	PCS Modules	Short-circuit failure	• Minor physical damage, outage	Experience and track record of supplier– • Green if established • Amber if new and own-brand	Low risk (yellow)
BATTERY	Transport	• Physical damage • Toxic chemicals • Explosion	• Delay to commissioning • Early failure • Physical damage	• Appropriate for technology type • In accordance with shipping legislation	Low risk (yellow)
	Off-loadin	• Physical damage • Toxic chemicals • Explosion	• Delay to commissioning • Early failure • Physical damage	• Method statements for off-loading and installation	Very low risk (green)
	Installation	• Physical damage • Toxic chemicals • Explosion	• Delay to commissioning • Early failure • Physical damage	• Design for access for e.g. fork lift - replacement mechanism suitable for weight	Very low risk (green)
	Battery Management System (BMS)	• Over / under-charging • Damage and fire	• Quality dependence: if a good system - single until replacements, if not, possibly whole system replacement	• Supplier and experience of BMS designer – importance can be overlooked by new suppliers	Very low risk (green)
	Commissioning	• Over / under-charging • Damage and fire	• See BMS	• See below	Very low risk (green)
	Operation	• Over / under-charging • Damage and fire • External physical damage	• See BMS • Zero impact to catastrophic damage	• See below • Locational and context required	Very low risk (green)
ANCILLARY CONTROLS	Environmental controls	• Poor operating conditions	• Reduced life, early replacement	• Set for technology type, maintenance	Very low risk (green)
	Fire-suppression	• Failure to operate	• Physical damage to more than affected unit	• Effect on other units under operation; maintenance regime	Very low risk (green)

Note: Rating is post-mitigation (assuming the recommended precautions have been taken from suppliers and methods)

Key: ● Very low risk ● Low risk ● Medium risk ● High risk

Commercial risks

The majority of battery storage opportunities are capital-intensive and the main risk is loss of income streams due to multiple and short-term uncertainties that could compromise the return on investment (Exhibit 8). Managing uncertainty is complicated by the considerable variability in skills and experience across a project.

System integration is another major risk and includes:

- Hedging opportunities: Hedging against price uncertainty or volatility, and potential loss of income.
- Lost opportunity costs: Technical failure resulting in low sales from the renewable generation, additional costs for an unplanned activity, and loss of additional income streams caused by non-delivery of ancillary services (where the market is favourable), which may include penalty payments for lack of availability.

However, system integration risks can be addressed by the purchaser of the storage technology by transferring risk to an expert supplier through an engineering, procurement, and construction or engineering, procurement, installation and commission contracts (EPC or EPIC, respectively). This gives a single contracted entity the responsibility of managing system integration and many other installation-related risks.

Operational risk is more often in the power conversion system (PCS) and BMS. Co-locating battery storage with another asset does not necessarily increase risk for third party liability, as the two assets can be positioned to minimise incidents, where one could impact the other and vice versa. However, third party risks can arise when battery manufacturers develop their own bespoke PCS[18]. Whilst PCSs are mature and used in most types of renewable energy plants, bespoke products can carry risks with a single-supplier (e.g. limited support and spares for PCS elements).

Third-party damage could be caused unintentionally, particularly by other activities near to the storage plant (e.g. during the installation of a new electricity cable the supply to the battery is cut-off leading to loss of revenue). Intentional physical damage can be mitigated through monitored security systems, although electronic hacking (via communication routes intended for metering, remote monitoring of battery health and control) would also cause damage.

It is possible for the battery, PCS and network connection equipment to be damaged by unauthorized control if not specifically designed to analyse the control being requested. However, this is a very low risk and it is more likely that losses in revenue will be measured in days with a recommendation to maintain systems more effectively.

The quality of the device or component is another consideration for the engineer, as those designed with minimal margins are under maximum stress for most of their working life, and can lead to cascade failure. This has occurred in solar farms. It is, therefore, important to use a reputable supplier and ensure compliance with local grid codes.

Exhibit 8: Risk profile card: Commercial assessment of a battery storage project

COMPONENT	SUB-ELEMENT	RISK	POTENTIAL IMPACT	QUESTIONS TO ASK	RATING
SYSTEM INTEGRATION	PCS	• Failure to operate	• Inability to trade and operate • Potential downtime	• Experience on system design • Experience on implementation	🟡
	Communications	• No communication • No knowledge • Control on trading	• At best don't know what has been sold, at worst unable to take advantage of high tariffs	• Local communications standards • Dependencies on communications	🟠
	Despatch	• Not reacting to grid requirements	Reduced earnings	• Understanding of market • Understanding of income streams	🟠
	Data security	• Third party disruption	• Loss of income • Disruption	• Security measures	🟡
THIRD PARTY RISKS	Impacts of third parties – intentional	• Vandalism • Sabotage • Terrorism	• Loss of earnings • Loss of plant	• Location risks	🟡
	Impacts of third parties – non-intentional	• Nearby works and activities	• Loss of earnings • Loss of plant	• Local legislation • Signage • Clearances	🟠
	Impacts on third parties – people	• Explosion • Toxic chemicals	• Loss of earnings • Loss of plant • Loss of life • Damage to life	• Signage • Clearances in location • Restrictions on nearby activity	🟡
	Impacts on third parties - plant	• Explosion • Toxic chemicals	• Loss of earnings • Loss of plant • Loss/damage of other buildings and equipment	• Signage • Clearances in location • Restrictions on nearby activity	🟡

Note: Rating is post-mitigation (assuming the recommended precautions have been taken from suppliers and methods)

Key: 🟢 Very low risk 🟡 Low risk 🟠 Medium risk 🔴 High risk

Market risks

The market for battery storage technologies is rapidly evolving and has changed considerably over the past decade[19]. There are now many more participants within the storage industry. Some are well-funded and give the impression they have sufficient capacity to meet high levels of demand. However, there is a risk of over-capacity in the market, as investment has been made ahead of developing projects with sufficient reliability and certainty in their business models to sustain sales (Exhibit 9).

Many suppliers may be located in geographic areas away from the demand, whilst others don't have sufficient liquidity and reputation to sustain investment. For example, a large battery installation of 10 MW, requires US$10-15 million of battery cells. This represents a sizeable investment and a new market entrant is unlikely to give sufficient confidence and certainty to an investor to justify purchase at this scale.

Battery manufacturers are still choosing to produce their cells in different formats with changing characteristics. In addition, the way that cells are linked together and operated by the BMS means that in the event of one or more cells failing, it may not be possible to replace those cells without the need for significant alterations to be made. For this reason, reliable and enduring manufacturers are generally preferred.

The track record of new manufacturers within the industry has not been good, with a number of high profile new entrant manufacturers either departing from the business or being taken over by another supplier. The most enduring suppliers tend to be those who have an established business model, cover other parts of the industry or provide several battery technologies. This gives them confidence and the ability to be able to withstand minor disturbances in the storage market.

Exhibit 9: Risk profile card: Market assessment of a battery storage project

COMPONENT	SUB-ELEMENT	RISK	POTENTIAL IMPACT	QUESTIONS TO ASK	RATING
SUPPLIER VOLUME	Over-capacity	Suppliers drop out	• Drop current projects • Loss of spares to operational projects	• Supplier history • Motivation • Commitment to the sector	Medium risk (orange)
	Insufficient liquidity Insufficientreputation	Suppliers drop out	• Drop current projects • Loss of spares to operational projects	• Supplier history • Motivation • Commitment to the sector	Medium risk (orange)
NEW ENTRANTS	Commitment	May drop-in and drop-out	• Drop current projects • Loss of spares to operational projects	• Motivations for entering the sector • Funding sources	High risk (red)
	Experience	May overlook key technology issues	• Failures of PCS, BMS etc. lead to loss of income • Replacement design • Supply all system costs	• Evidence of learning from experiences suppliers • Smaller scale trials	Medium risk (orange)
TECHNOLOGY DEVELOPMENT	Module development	Development removes backward compatibility	• Replacements, scheduled or unscheduled • Need wider system re-design and re-configuratio	• Evidence of backward compatibility of systems developed to date	Medium risk (orange)
	New battery technologies	Suitability for application	• Major system failure (though recognising there remains always the potential for a disruptive positive technology improvement)	• is diversification driving market entry, rather than catering to market specifically	High risk (red)
GEOGRAPHY	Supplier remote from demand	Spares supply time	• Cost of spares • Delay to repairs	• Volume of supply in interest market • Spares strategy	Low risk (yellow)
REPUTATIONAL	Environmental	Public relations disaster	• Damages to firm's reputation • Lost revenue • Increased operating cost • Increased capital costs • Increased regulatory costs • Destruction of shareholder value	• Appropriate mitigation, permits • Contingency plans in place	Low risk (yellow)

Note: Rating is post-mitigation (assuming the recommended precautions have been taken from suppliers and methods)

Key: ● Very low risk ● Low risk ● Medium risk ● High risk

Natural events risks

Extreme weather conditions are not expected to cause problems, provided the building or other structure, which contains the battery, has been suitably constructed and maintained (Exhibit 10). Batteries are of sufficient weight that they would not be dislodged by even the strongest hurricanes or typhoons. However, damage caused by combinations of wind or waves, including a tsunami, is not easily predictable.

Water damage is severely hazardous for batteries and as a minimum, systems should be built above the credible flood levels. Some batteries, such as sodium types, could react violently with water in the case of submersion. However, the high potential for damage due to water also extends to mature technologies such as lead-acid, as the high DC voltages can cause high short circuit currents, fires and consequent damage to both batteries and PCS. In the event of submersion, even for a short period, most electrical components will fail or no longer be safe to operate. Hence, if the flood level reaches batteries and PCS they should be regarded as a total loss. It can be important to protect battery systems against snow, for similar reasons, especially if there is risk of snow melt.

Earthquake zones do not necessarily exclude battery storage. For example, most battery installations in Japan are in areas of high seismic activity, where they provide reliable power supplies in the event of local power system failure. Earthquake damage can be limited by suitable design in accordance with local requirements, and building design codes for seismic regions. Adequate foundations, for example, together with racks for the batteries, which are of sufficient strength to prevent over-toppling during periods of seismic activity, have been shown to be effective. However, the greatest danger is when an earthquake occurs during a period of installation or maintenance.

Exhibit 10: Risk profile card: Natural events assessment of a battery storage project

COMPONENT	SUB-ELEMENT	RISK	POTENTIAL IMPACT	QUESTIONS TO ASK	RATING
NATURAL EVENTS	External fi e	• Loss of electrical supply	• Damage to batteries through being cut-off	• Provisions for self-supply of reserves	● (yellow)
	Storm	• Loss of electrical supply • Damage to buildings	• Batteries themselves largely unaffected • Damaged if lose connection • Cost of replacements • Building repair	• Design of building and provision for self-supply of reserves	● (orange)
	Flood, including rising water and snow melt	• Damage to chemical batteries	• Total loss of batteries • Potential fire and chemical pollution • Corrosion products • Cleaning costs	• Location flood risk • Elevation • Bunding protection	● (orange)
	Earthquake	• Movement	• Damage as per transport and installation	• Building design to withstand earthquake	● (green)

Note: Rating is post-mitigation (assuming the recommended precautions have been taken from suppliers and methods)

Key: ● Very low risk ● Low risk ● Medium risk ● High risk

What mitigation options and strategies exist for storage?

Each type of battery storage system has its own specific risks and different manufacturers have different approaches to mitigating them (Exhibit 11). The mitigation ethos for insured risk needs to consider the role of international standards for compliance, manufacturers warranties, combined with the deployment history of a technology, which can provide a proxy for the quality of design and product assurance.

Various mitigation methods can be used. These include, for example, fusible links and fire suppression systems and BMS. The battery could be placed in a low state-of-charge to minimise stored energy during transport and installation. Shipping may require specialist procedures and compliance with international regulations, such as those designated by the UN. High temperature batteries, for example, are transported with the active materials in a solid state (i.e. frozen at shipping temperatures and hence do not pose a hazard). Nevertheless, all batteries need to be handled with care and inspected before switching-on.

There are also some general mitigations that should be applied as good practice whatever the technology. These are part of a comprehensive asset management programmed, good operation and maintenance, remote monitoring, access control, fast-response site-support, and the ability of systems to be robust and effect safe shutdown in the case of malfunction.

Exhibit 11: Main risk mitigation measures by battery technology

BATTERY TECHNOLOGY	MAIN RISK	MITIGATION MEASURES
LEAD-ACID (MATURE)	Overcharging and high-rate charging can evolve hydrogen.	• Mitigate by using passive or active ventilation and BMS • BS EN 50272-2:2001 sets requirements
NICKEL-BASED	As above	• As above
SODIUM-BASED	Liquid sodium reacts violently with water. Liquid metal from damaged cell could cause short-circuits and propagate faults through a module leading to a fire.	• Mitigation by sealing modules from water ingress • Packing in sand to absorb metal • Use gas-detection systems for reaction products linked to a BMS
LITHIUM-BASED	Thermal runaway and a subsequent cascade affecting a module. Flammable gases can combust in low oxygen conditions due to the breakdown of electrolytes.	• Mitigate using a BMS that controls the state and rate of charge of each individual cell • Mitigate using a gas detection and suppression system
FLOW	Large quantities of very acidic electrolyte.	• Mitigation using bund systems • Shields to protect operators • Leak-detection systems with redundancy as part of the BMS • Keep spill kits and acid neutralising equipment on-site

V. CONCLUSIONS

Battery storage is an exciting and potentially a 'game-changing' technology to help facilitate the transition of electricity networks from centralised power grids to more distributed ones globally. One of the biggest drivers for this has been the need to deploy storage applications throughout the electricity value chain to enable greater penetration of variable renewable generation.

The versatility of battery storage and the rapid advances in technology innovation are providing numerous other operational benefits in parallel, such as load shifting and power quality, improved system flexibility, and more efficient utilisation of electricity networks. Battery storage has matured in recent years and is expected to continue to grow, although this is not a universal picture. Cost reduction is one of the major barriers to achieving widespread deployment and is falling faster for some technologies (e.g. lithium-ion and flow batteries) compared to others.

Clearly, the international energy markets are anticipating big things from the battery storage sector and may be looking at batteries as the panacea for all their problems. Whist it is true that energy storage offers a suite of applications to fulfill multiple roles, across both supply and demand-side activities, applications need to be considered on a case-by-case to ensure technical and commercial risks are adequately considered.

The continued uptake of battery storage technologies will further grow the knowledge and evidence-base needed to promote confidence in the energy industry. This is a journey that needs continued government investment and support from more countries worldwide. In Australia, for example, support for battery storage is moving towards a market-led roll-out, but there is still an urgent need for demonstration projects to help boost confidence within the energy industry.

A common misconception of the storage industry, is that battery storage must be implemented at the site of generation and can only be used to time shift energy. In reality, the market mechanisms to support time-shifting are not in place for much of the industrialised world, although other services such as standby power, fuel saving, tariff avoidance and ancillary services are possible.

There is an opportunity for countries willing to adopt effective policies and regulations, and provide the necessary support for projects, to take a leading role in the transition towards a future of decentralised renewable electricity by embracing the uptake of battery storage technologies.

VI. REFERENCES

1 U.S. Energy Information Administration (2016). International Energy Outlook 2016. Report: Chapter 5.

2 Decarbonisation is the reduction of carbon dioxide from energy sources.

3 Institute, S. E. (2013). Leading the Energy Transition: Electricity Storage.

4 According to the UK National Grid, this phrase describes a power source that doesn't produce a constant amount of energy (e.g. a wind farm, which will vary according to how windy it is).

5 The Japanese government has set an explicit target of capturing 50% of the world's projected global storage battery market by 2020, which the plan estimates to be valued at ¥20 Trillion. (see Ministry of Economy, Trade and Industry (METI), (2014), Fourth Strategic Energy Plan).

6 According to the UK National Grid, balancing the system to make sure that demand is met by supply is one of the most important they do and it is becoming more challenging as intermittent generation, such as wind power, becomes a bigger part of the overall energy mix.

7 Malhotra, A., et al. (2016). Use cases for stationary battery technologies: A review of the literature and existing projects, Renew. Sustain. Energy 56: 705–721.

8 Boicea, V. (2014). Energy storage technologies: the past and the present, Proc. IEEE 102, 1777–1794.

9 Poulikkas, A. (2013). A comparative overview of large-scale battery systems for electricity storage, Renew. Sustain. Energy Rev. 27 778–788.

10 AECOM (2015). Energy storage study: funding and knowledge sharing priorities. Australian Renewable Energy Agency.

11 Institute, S. E. (2013). Leading the Energy Transition: Electricity Storage, and.

12 Alotto, P., et al. (2014). Redox flow batteries for the storage of renewable energy: A review. R. S. En. Reviews 29: 325-335.

13 Curtailment is a reduction in the output of a generator from what it could otherwise produce given available resources. It is used to address issues on the electricity supply system (e.g. transmission congestion). For a wind farm or solar project owner, it could impact scheme economics, but an energy storage facilities could provide the ability to store power during curtailment.

14 Agency, I. E., (2014). Technology Roadmap Energy storage.

15 Used to reduce electrical power consumption during periods of maximum demand on the power utility. Thus saving substantial amounts of money due to peaking charges.

16 Submission to the Independent Review into the Future Security of the National Electricity Market, Baldwin K and Franklin E, Australian National University Energy Change Institute (6 Mar 2017).

17 Ribiere, P., et al. (2012). Investigation on the fire-induces hazards of li-ion battery cells by fire calorimetry, Energy Environ. Sci., and Horn, Q. (2014). Failure modes unique to large format cells and battery systems, in: NAATBatt Annual Meeting and Symposium.

18 PCS's are used to convert between AC to DC and vice versa, similar to that used in HVDC applications. Transformers are used to change the AC voltage from the network voltage to the operating voltage of the PCS. Modern PCS are assembled from semiconductor components, unless the system is thermo-dynamic such as compressed-air energy storage.

19 Muñoz, A., et al. (2016). Overview of storage technologies. Horizon 2020 research and innovation programmed under Grant Agreement No. 645963.

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