

# Second-Life Batteries for Ancillary Services

## Year 2 Stakeholder Review

**May 8, 2026**

Work conducted for Dr. Cyrille Decès-Petit at National Research Council (Contract #1033592)

Work conducted by Chris White (PhD) and Lukas Swan (PhD) at Dalhousie University

Principal Investigator: Lukas Swan, PhD, PEng  
Professor, Department of Mechanical Engineering  
Director, Renewable Energy Storage Laboratory  
Dalhousie University  
Sexton Campus, 5269 Morris St, Halifax, Nova Scotia, B3J 0H6, Canada  
T: 902-830-0349, E: [Lukas.Swan@Dal.Ca](mailto:Lukas.Swan@Dal.Ca), W: <http://resl.me.dal.ca>

### **Abstract**

A growing number of second-life battery companies are entering North America's stationary energy storage market as the demand for both electric vehicles and electricity grid energy storage continues to rise. These companies have many potential revenue streams available to them, including electricity grid ancillary services, but the unique characteristics of second-life batteries also present many challenges beyond those faced by conventional battery developers. In 2025, we published a literature review detailing the technical aspects of second-life batteries and ancillary services based on published research, industry reports, and our own laboratory expertise. We now build upon that work through direct engagement with industry stakeholders, including eight North American second-life battery companies and five Canadian electrical utilities and electricity system operators. After speaking with these stakeholders in a series of interviews, we have compiled in this report an aggregate perspective on the current state of the North American second-life battery industry as well as its present opportunities and challenges. We find that although the industry is largely still in an exploratory stage, with nascent supply chains and minimal progress towards competing in the ancillary services space, second-life battery companies are working to overcome major regulatory barriers that are inhibiting industry growth and developing innovative technological and commercial solutions to compete with conventional battery energy storage at different scales. We also find that other stakeholders such as utilities and electricity system operators seem open to (and certainly not discriminatory toward) this technology, and its inclusion in the grid. Even so, the second-life battery industry still has a lengthy developmental curve ahead, subject to dynamic market forces. We end by recommending 10 potential steps that governments can take to help support the growth of this industry in the utility scale.

# Table of Contents

1	Introduction.....	5
1.1	Research objective .....	5
1.2	Research team .....	5
1.3	Research methods.....	6
1.4	Disclaimer .....	6
1.5	Overview of the report.....	7
2	Regulatory Frameworks Related to Second-life Battery Systems .....	8
2.1	Standards and certifications.....	8
2.1.1	General lithium-ion batteries .....	8
2.1.2	Electric vehicle batteries.....	9
2.1.3	Stationary batteries .....	10
2.1.4	Second-life batteries.....	11
2.1.5	Battery energy storage systems .....	11
2.2	Jurisdictional approvals.....	12
2.2.1	System installation .....	12
2.2.2	Electricity grid interconnection .....	13
3	Perspectives of Second-life Battery Companies.....	14
3.1	Projects and use cases .....	14
3.2	System design .....	14
3.2.1	Battery acquisition.....	15
3.2.2	System architecture.....	15
3.2.3	Battery management.....	15
3.2.4	Thermal management .....	16
3.3	Regulatory challenges .....	17
3.3.1	UL 9540 and UL 1973 certifications .....	17
3.3.2	UL 1974 certification .....	18
3.3.3	Local permitting.....	18
3.3.4	Alternative pathways.....	19
3.3.5	Revision of UL certification standards .....	20
3.4	Economic challenges .....	21
3.4.1	Competition with new batteries.....	21
3.4.2	Battery supply chains .....	21
3.4.3	Regulatory impacts.....	22
3.4.4	Product warranty.....	22
3.4.5	Project financing and insurance .....	23
3.4.6	Research and investment .....	23
3.5	Technical challenges .....	24

3.5.1	Variance in battery design .....	24
3.5.2	Variance in battery degradation .....	24
3.5.3	Thermal management and safety .....	25
3.5.4	Battery performance limitations .....	27
3.5.5	Monitoring and control systems.....	28
3.6	Advantages of second-life batteries.....	28
3.6.1	Manufacturing standards .....	29
3.6.2	Infant mortality .....	29
3.6.3	Power capability .....	29
3.6.4	Control optimization.....	29
3.6.5	Battery replacement.....	29
3.6.6	Market entry points.....	30
4	Perspectives of Canadian Utilities and System Operators .....	31
4.1	Opportunities for battery energy storage .....	31
4.2	Interconnection considerations .....	32
4.3	Economic considerations .....	33
4.4	Confidence building .....	34
5	Conclusions and Recommendations .....	35
5.1	A diverse and evolving industry .....	35
5.2	Challenges and solutions.....	35
5.3	Openness from utilities and electricity system operators.....	36
5.4	Recommendations to support industry growth .....	37
5.5	Acknowledgements.....	38
	References .....	39

## List of Abbreviations

AC	Alternating current
AHJ	Authority having jurisdiction
BESS	Battery energy storage system
BMS	Battery management system
BTM	Behind the meter
CEC	Canadian Electrical Code
CMVSS	Canadian Motor Vehicle Safety Standards
CSA	Canadian Standards Association
DC	Direct current
DERMS	Distributed energy resource management system
ECE	Economic Commission for Europe
EV	Electric vehicle
FMVSS	Federal Motor Vehicle Safety Standards
FTM	Front of the meter
IBC	International Building Code
ICC	International Codes Council
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IP	Ingress Protection
ISO	International Organization for Standardization
LFP	Lithium iron phosphate
MRO	Midwest Reliability Organization
NBC	National Building Code of Canada
NEC	National Electric Code
NERC	North American Electric Reliability Corporation
NESC	National Electrical Safety Code
NFC	National Fire Code of Canada
NFPA	National Fire Protection Association
NPCC	Northeast Power Coordinating Council
NRTL	Nationally recognized testing laboratory
OEM	Original equipment manufacturer
RFP	Request for proposal
SAE	Society of Automotive Engineers
SLB	Second-life battery
SOC	State of charge
SOH	State of health
SPE	Special Publication Electrical
UL	Underwriters Laboratories
UN	United Nations
USD	United States Dollar
WECC	Western Electricity Coordinating Council

# 1 Introduction

With the concurrently accelerating trends of electric vehicle (EV) battery production, their future retirement, and the need for stationary energy storage in the electricity grid, the repurposing of used EV batteries into second-life battery (SLB) projects is poised to play a role. This is evolving with the needs of electricity systems while enhancing circularity in the EV battery life cycle. But with new-build battery energy storage systems (BESS) already scaling economically to meet growing demand, SLB companies must find ways to become economically and technologically competitive in order to fulfill their tremendous potential as a more sustainable BESS solution.

SLBs can provide many different services to electricity grids, such as peak shaving, energy arbitrage, demand-side management, transmission upgrade deferral, demand charge reduction, and backup power [1]. The growth of renewable, inverter-based resources also creates need for ancillary services such as frequency regulation, frequency response, spinning and non-spinning reserves, and voltage support [1], and this presents another potential opportunity for SLBs to support the ongoing transformation of electricity systems. However, many questions remain about how SLB companies enter into the utility space, and how to surmount the barriers and challenges.

In the interest of understanding the present reality of opportunities and challenges facing SLB companies in the ancillary services sector, and the industry in general, we have undertaken a stakeholder research project aimed at obtaining information and perspectives directly from those who are doing the work on the ground.

## 1.1 Research objective

The objective of this research project is to pull together a wide range of first-hand industry perspectives on the current status of the SLB industry in North America, identify the main barriers inhibiting industry growth (particularly in regards to ancillary services), and compile our findings into a public report that can aid the Canadian government and other stakeholders in supporting the growth of the SLB industry. To this end, we engaged with second-life battery companies (who provide SLB systems), electricity utilities (who procure SLB systems as assets), and electricity system operators (who signal SLB systems for services). While the primary focus of this study is ancillary services, the report encompasses all energy storage services that we found to be active in the North American SLB industry.

## 1.2 Research team

Since its founding in 2010, the Dalhousie University Renewable Energy Storage Laboratory has gained a wealth of experience in the handling, modeling, repurposing, and experimental testing of used EV batteries at cell, module, pack, and system levels. Much of this work has been done in collaboration with various research groups, SLB companies, and other electricity sector stakeholders across North America. We have hands-on experience with more than a dozen unique EV battery types featuring different capacities, voltages, form factors, chemistries, cell formats, and health levels. We have also worked extensively with different battery management systems (BMS), power conversion systems, and thermal management systems. Our range of hands-on experience, combined with our wide network of contacts across the industry, makes us uniquely positioned to undertake this stakeholder research project and ask the right questions to the right people.

### **1.3 Research methods**

To achieve our research objective, we first built a list of key industry stakeholders that have valuable first-hand perspectives to share. This list grew out of a combination of our existing industry contacts, first-degree connections, and internet searches. We then sent inquiries to these stakeholders via email and business networking to share the details of our study and invite individuals to participate in a 30-minute videoconference interview.

We interviewed a total of eight SLB companies across Canada and the United States between December 2025 and March 2026. Three additional SLB companies were contacted but did not respond to our inquiries. We asked the interviewees questions about their businesses, SLB technologies, commercial projects, primary revenue streams, and the main challenges or barriers they have encountered while developing projects in the nascent SLB industry. The eight interviewed SLB companies represent a wide range of developmental stages, geographical locations, technological preferences, and commercial approaches. Interviewees generously gave us detailed answers to many questions, but due to different approaches and levels of experience, were not always able to answer all questions.

During the same time span, we also interviewed five Canadian electrical utilities and electricity system operators. These five entities are based in three unique Canadian jurisdictions:

- British Columbia, which lies at the western edge of the continent and features a vertically integrated electricity system.
- Ontario, which sits in the middle of the continent and features well-established competitive procurement auctions operated in various electricity markets.
- Nova Scotia, which hangs from the eastern edge of the North American grid and has recently broken from its longstanding vertically integrated model by introducing a new independent electricity system operator.

We asked the interviewees about the current status and future prospects of battery energy storage in their respective jurisdictions, the technical requirements that BESS projects must meet before being granted approval for system interconnection, and any potential advantages or disadvantages they foresee regarding SLB projects vs new-build BESS. Again, interviewees were generous with their answers, but due to different levels of experience and areas of expertise, were not always able to answer all questions.

### **1.4 Disclaimer**

All interviewees were informed at the beginning of each interview regarding the intent of our research and how the information they communicated would be documented in a public report. We have made our best effort in this report to avoid presenting information in a way that readers could use to associate specific interview outcomes with specific organizations. We have honoured any expressed requests to keep specific pieces of shared information off the record, and we do not reveal in this report the personal identity of any individual interviewees.

## 1.5 Overview of the report

The remainder of this report is divided into the following sections:

- Section 2 provides information on the various certification standards and jurisdictional approval processes that influence SLB project development in North America.
- Section 3 describes findings and outcomes of our conversations with North American SLB companies regarding the status of their technological and commercial development and the main challenges they have encountered.
- Section 4 reviews the perspectives of Canadian utilities and electricity system operators regarding the demand for energy storage in their jurisdictions, their requirements for BESS to connect to their systems, and the potential hurdles they see for SLB companies.
- Section 5 presents our main conclusions and recommendations.

Note that this report builds upon a 2025 report published as “Second-Life Batteries for Ancillary Services: Literature Review and Technical Assessment” [1], which details SLB technology in general, describes various ancillary services, and introduces the vocabulary specific to this sector. We expect that readers are familiar with our 2025 report, as the many technical concepts described in the 2025 report will not be reiterated here.

## **2 Regulatory Frameworks Related to Second-life Battery Systems**

Our conversations with SLB companies, utilities, and electricity system operators revealed that many of the major barriers for SLB projects are regulatory in nature. To preface our review of these barriers, this section will provide background information on the various regulatory frameworks that relate to SLB projects.

### **2.1 Standards and certifications**

Standardized safety certifications give authorities and customers confidence that products are reliable and safe to use. Given that lithium-ion batteries are capable of causing dangerous incidents in both consumer products, EVs, and BESS, safety certifications are especially important. The certification requirements are developed by accredited standards organizations, while nationally recognized testing laboratories (NRTLs) carry out the required test procedures and issue certifications for battery products.

In Canada and the United States, the most relevant standards organizations include Underwriters Laboratories (UL), CSA Group (formerly Canadian Standards Association), Institute of Electrical and Electronics Engineers (IEEE), Society of Automotive Engineers (SAE), and National Fire Protection Association (NFPA). Relevant international codes and standards are also developed by International Electrotechnical Commission (IEC), International Organization for Standardization (ISO), International Code Council (ICC), and United Nations (UN). Some examples of NRTLs in North America are UL, CSA Group, Intertek, TÜV, QAI, and QPS. Note that UL and CSA are accredited both to develop safety standards and to conduct certification testing according to those standards.

#### **2.1.1 General lithium-ion batteries**

For the safety of lithium-ion batteries at the individual cell level, UL 1642 [2] specifies a series of tests to verify that the cell does not catch fire, explode, vent, or leak under abuse: electrical tests, which include short circuit, overcharge, and forced discharge; mechanical tests, which include crush (crushing the cell), impact (dropping a weight onto the cell), shock (high acceleration), and vibration; environmental tests, which include heat exposure, temperature cycling, altitude simulation (low pressure); and a projectile test. SLB companies repurposing EV batteries in North America will generally work with cells that were originally certified to UL 1642. Internationally, IEC 62133-2 [3] serves as a similar safety certification standard specifying requirements and tests for the safe operation of portable lithium-ion cells and batteries. IEC 61960-3 [4] also sets lithium-ion cell performance benchmarks such as, capacity, impedance, and cycle life. Another notable safety standard currently in preparation is NFPA 800, which will cover the full lifecycle of battery systems including manufacturing, transportation, storage, recycling, and end of life [5], [6].

To ensure the safety of lithium-ion batteries during transport, subsection 38.3 of the UN Manual of Tests and Criteria [7] specifies eight safety tests, including altitude simulation, rapid temperature fluctuation, vibration, mechanical shock, external short circuit, impact/crushing, overcharge, and forced discharge. Regulations set by both Transport Canada and the United States Department of Transportation (and most governments worldwide) mandate UN 38.3, meaning that SLB companies must comply with UN 38.3 in order to ship their SLB products. At present, most lithium-ion cells are

built in China, Korea, Japan, Europe, and the United States, and will require shipping to Canada. IEC 62281 [8] is another international standard that largely aligns with UN 38.3.

Another relevant lithium-ion battery standard in the context of SLBs is UL 3601 (*Standard for Measuring and Reporting Circularity of Li-ion and Other Secondary Batteries*) [9]. This standard offers a UL ECOLOGO Certification for battery products based on criteria such as durability, recyclability, reusability, and recoverability. Similarly, CSA is developing V801 (*Battery Circularity Standard*) [10]. SLB companies should benefit if EV battery manufacturers are incentivized to design their batteries for enhanced circularity.

### **2.1.2 Electric vehicle batteries**

While UL 1642 applies to lithium-ion cells, UL offers additional standards for lithium-ion batteries assembled into packs for EV applications. UL 2580 [11] applies to battery packs for EVs (e.g., cars, trucks), and UL 2271 [12] applies to battery packs for light EVs (e.g., e-scooters, e-bikes). These standards specify mechanical, electrical, and environmental abuse testing requirements similar to cell-level tests specified by UL 1642, but carried out at the module or pack level to account for the effects of the balance of plant (e.g., enclosures, electronics, thermal management) which may increase safety but may also introduce additional risks. Examples of increased safety are non-flammable enclosures, while examples of increased risks are propagation of thermal failures from cell to cell inside a module. Tests include mechanical shock, crush, impact, vibration, overcharge, overdischarge, imbalanced charging, short circuit, high-temperature endurance, thermal cycling, salt spray, water immersion, insulation resistance, and thermal safety.

In the North American EV industry, SAE standards complement the UL 2580 certification standard. Compliance with SAE standards is voluntary. They serve as industry guidelines, but are generally adhered to across the industry. The most important SAE standards impacting EV battery manufacturing and testing are listed below:

1. SAE J1798 [13] provides test methods and criteria for evaluating EV battery module performance.
2. SAE J2344 [14] provides overarching guidelines for EV safety.
3. SAE J2929 [15] defines acceptable safety criteria for EV batteries (mainly that a battery must not rupture, catch fire, or explode during testing).
4. SAE J2464 [16] specifies a standard EV battery abuse testing procedure (e.g., mechanical shock, drop, crush, nail penetration, roll-over, vibration, immersion, overcharge, overdischarge, short circuits, heat exposure, thermal cycling, cycling without thermal management, thermal propagation).
5. SAE J2380 [17] recommends vibration testing for EV batteries.
6. SAE J1766 [18] defines testing criteria for EV battery safety in vehicle crash scenarios (the battery must remain attached to the vehicle, must not leak significant electrolyte, and must retain electrical isolation).
7. SAE J2950 [19] recommends safe practices for EV battery transport and handling.

In the United States Federal Motor Vehicle Safety Standards (FMVSS) and the Canada Motor Vehicle Safety Standards (CMVSS) outline regulated minimum requirements covering many different aspects of motor vehicle design, performance, and safety, frequently citing SAE standards. One important FMVSS standard for EV batteries is FMVSS 305 [20], which essentially makes the voluntary crash test requirements of SAE J1766 enforceable by law (a newer FMVSS 305A standard will be enforced starting in 2027). EV batteries also are generally rated with ingress protection classification IP67 as per IEC 60529 [21], meaning they are fully protected against dust and can withstand immersion in 1 m of water for 30 minutes.

International EV battery standards include IEC 62660 (for performance and safety) [22-25], ISO 12405-4 (for performance) [26], ISO 6469-1 (for safety) [27], UN ECE R100 (for EV) [28], and UN ECE R136 (for light EV) [29]. Major automotive manufacturing countries outside North America (e.g., China, Germany, South Korea) also have their own EV standards.

While SLB companies do not need to be concerned with automotive standards, the strict nature of EV battery safety standards is an important point when considering the safety of SLB systems. If a repurposed EV battery was held to such high safety standards for EV service, it lends confidence to how safe that battery is to operate in a stationary application (subject to its handling and additional balance of plant necessary to adapt it to second life). This will be considered further in Section 3.3.

### **2.1.3 Stationary batteries**

Batteries intended for stationary energy storage applications require their own specialized certifications to ensure they can operate safely. The main standard in North America is UL 1973 (*Batteries for Use in Stationary and Motive Auxiliary Power Applications*) [30], which outlines a set of battery construction and design requirements as well as a series of battery performance and safety tests. While UL 1973 is primarily designed for lithium-ion batteries, the standard includes exceptions or alternatives when different considerations are necessary for other battery chemistries used in stationary applications. Internationally, IEC 61427 [31], [32] and IEC 62619 [33] provide standard test procedures to respectively certify the performance and safety of stationary batteries in renewable energy applications, with tests designed to be chemistry agnostic.

For construction and design, UL 1973 covers materials, enclosures, wiring, electrical spacings, electrical isolation, grounding, BMS, protective circuits, controls, thermal management, electrolyte containment, and cell design. Commonly, the BMS is certified separately under CSA C22.2 No. 340 [34], which aligns with UL 1973 requirements. For performance and safety tests, UL 1973 describes electrical, mechanical, and environmental tests such as overcharge, over-discharge, short circuit, imbalanced charging, vibration, shock, crush, impact, drop, pressure release, thermal cycling, moisture resistance, external fire exposure, and internal fire exposure (i.e., thermal runaway).

**Importantly, EV batteries are not certified under UL 1973. This means that used EV batteries in North America will not have the necessary certification to be repurposed into stationary applications. SLB companies are therefore responsible for obtaining UL 1973 certification on used EV batteries they wish to repurpose. This will be elaborated on in Section 3.3.**

#### **2.1.4 Second-life batteries**

Currently, the only North American certification standard created specifically for SLBs is UL 1974 (*Evaluation for Repurposing or Remanufacturing Batteries*) [35]. First published in 2018 and revised in 2023, UL 1974 outlines a procedure for testing, grading, and sorting used EV batteries during repurposing, thereby offering certification for the SLB manufacturing process rather than the actual SLB product. The latest 2022 edition of UL 1973 requires that any battery system using repurposed batteries must be certified under UL 1974, effectively linking the standards in terms of a pathway to approval.

UL 1974 requires that the cells of the repurposed battery be previously certified by the original equipment manufacturer (OEM), otherwise the SLB company must apply existing battery safety standards to ensure the cells are compliant. UL 1974 also recommends that repurposing companies adopt existing lithium-ion battery safety test methods (e.g., overcharge, thermal abuse, short circuit) and consider adjusting second-life operating limits based on how the test results compare to new batteries, but this is not mandatory.

For the repurposing process, the pack must be disassembled to the battery unit (i.e., either full packs, modules, or cells) that will be deployed in second life. UL 1974 then recommends a series of test protocols for evaluating the open-circuit voltage, high-voltage isolation, discharge capacity, internal resistance, BMS functionality, cycling performance, and self-discharge rate of acquired EV batteries so that underperforming batteries can be rejected. However, it is left up to the repurposing company to select appropriate pass/fail criteria for these tests. The main requirement of UL 1974 is that the repurposing company develop a grading system with which to rank battery test results, and that SLB systems be assembled using same-grade battery units to promote system homogeneity. UL 1974 also requires that an SLB system must be assembled from repurposed batteries of the same manufacturer and model.

Other recent standards have been published internationally, namely IEC 63330-1 (*Repurposing of secondary batteries - Part 1: General requirements*) [36] and IEC 63338 (*General guidance on reuse and repurposing of secondary cells and batteries*) [37], both published in 2024. IEC 63330-1 provides strict technical requirements for the repurposing procedure of lithium-ion batteries, while IEC 63338 offers general guidance and best practices for safe reuse and testing. One notable difference from UL 1974 is that the IEC standards require a battery to have its lifetime traceability data recorded if it is to be repurposed. Separate regulatory frameworks for battery traceability are also being developed. For example, in September 2025, SAE International published SAE J3327 [38] as a standard for EV battery traceability records.

#### **2.1.5 Battery energy storage systems**

While UL 1973 certification applies to stationary batteries at the module or pack level, UL 9540 [39] certification applies to a complete energy storage system, including the energy storage technology itself (e.g., batteries) and all other components (termed the “balance the plant”). UL 9540 addresses construction and testing requirements similar to UL 1973, but at the system level rather than the battery level. Internationally, IEC 62933 [40-56] provides a series of standards addressing the performance and safety of electrical energy storage systems.

System-level construction requirements under UL 9540 include materials, enclosures, electrical wiring and connections, electrical spacings and insulation, remote controls, communication systems, heating and cooling systems, piping systems, fire detection and suppression, power conversion equipment, and the energy storage technology itself. For a BESS, UL 9540 requires that the installed batteries and BMS be certified under UL 1973, and that the other system components be certified under other applicable standards. For example, the power conversion equipment must be certified under eligible standards such as UL 1741 [57] or CSA C22.2 No. 107.1 [58]. UL 9540 also specifies a wide range of system-level electrical, mechanical, environmental, and manufacturing and production tests that assess normal operations, dielectric voltage withstand, impulse, electromagnetic immunity, containment, leakage, strength, outdoor moisture exposure, seismic environment, electrical production, and production quality control.

Other than the fact that UL 9540 requires UL 1973 which in turn requires UL 1974 for SLBs, there is no explicit difference between the UL 9540 certification of an SLB system and a new-build BESS. Section 3.3 will describe some more nuanced certification challenges experienced by SLB companies in North America, primarily due to the lack of UL 1973 certification in EV batteries.

## **2.2 Jurisdictional approvals**

The final permits for BESS construction, interconnection, and commissioning ultimately depend on the authority having jurisdiction (AHJ) in a given project location, such as local fire chiefs, electrical inspectors, electricity system operators, and municipal officials. These AHJs review project designs, hazards, risks, safety features, and emergency response plans, and verify compliance with applicable fire codes, electrical codes, and building codes.

### **2.2.1 System installation**

BESS projects depend on various safety codes and regulations at different jurisdictional levels. In Canada, these include the National Fire Code of Canada (NFC), the Canadian Electrical Code (CSA C22.1 or CEC) the National Building Code of Canada (NBC), as well as provincial and municipal regulations. In the United States, relevant codes include the Fire Code (NFPA 1), the National Electric Code (NFPA 70 or NEC), the National Electrical Safety Code (IEEE C2 or NESC) [59], as well as state and municipal regulations. Some jurisdictions adopt international codes, such as the International Fire Code (IFC) and the International Building Code (IBC) issued by ICC.

The installation of an SLB project in North America should comply with the safety standards that apply to BESS. Electrical safety standards include CEC Section 64 (Canada only) [60], NEC Article 706 (for behind-the-meter systems) [61], and NESC Section 14 (for front-of-the-meter systems) , while fire safety standards include NFPA 855 [62] and IFC Section 1207 [63]. These standards in turn require that BESS project developers certify their systems under UL 9540 and carry out large-scale fire testing according to the UL 9540A [64] test method to assess fire propagation. NFPA 855 also calls for explosion prevention systems through the NFPA 69 standard [65] and/or explosion protection systems (i.e., deflagration venting) through the NFPA 68 standard [66].

Depending on the jurisdiction, a degree of discretion may be exercised by AHJs in the interpretation of local codes. While most AHJs do look for official UL certifications, NFPA compliance, etc., some AHJs

may be satisfied if a project developer can provide sufficient documentation that adequately demonstrates safety, and thus allow an alternate path or a special inspection and approval process.

## **2.2.2 Electricity grid interconnection**

Any generating or storage asset that connects to the North American electricity grid must comply with standards set by the North American Electric Reliability Corporation (NERC) and the applicable regional entity: Western Electricity Coordinating Council (WECC), Midwest Reliability Organization (MRO), Northeast Power Coordinating Council (NPCC), Reliability First (RF), Southeastern Electric Reliability Council (SERC), or Texas Reliability Entity (Texas RE). Each regional entity sets its own interconnection requirements on top of the more general NERC requirements. Three of the six regional entities have jurisdiction in Canada: WECC in British Columbia and Alberta, MRO in Saskatchewan and Manitoba, and NPCC in Ontario, Quebec, New Brunswick, Nova Scotia, and Labrador. Prince Edward Island, Newfoundland, Nunavut, the Northwest Territories, and the Yukon are “isolated” systems (i.e., not “bulk” systems) and therefore not formally covered by NERC. The NERC interconnection requirements are generally aligned with standards such as IEEE 2800 (transmission-level interconnections for inverter-based resources) [67] and IEEE 1547 [68] (distribution-level interconnections for distributed energy resources).

Electricity system operators within NERC also set their own jurisdictional interconnection requirements that cover the requirements of both NERC and the applicable regional entity while establishing any additional requirements specific to the jurisdictional grid in question. This means that an SLB company will have to comply with different interconnection requirements in different jurisdictions when developing a BESS project. Furthermore, the evolving nature of electricity supply and demand means that interconnection requirements in a given jurisdiction may be revised from one year to the next. Interconnection requirements typically include specific tests that verify whether a generation or storage asset can perform various key functions for the system operator in question, such as fault-ride through, voltage response, and frequency response, though these tests vary by jurisdiction. A given system operator may also require product certifications like UL 9540 before approving the interconnection, even if an AHJ permitted BESS installation without certification.

Jurisdictional interconnection requirements set the minimum standards that must be met in order to connect a generating or storage asset to the grid. However, meeting these standards does not guarantee that interconnection will be approved. The electricity system operator must first verify that the proposed interconnection will not create or exacerbate electromagnetic transients such as oscillations or dampening effects that could compromise grid reliability. An accurate model of the generating or storage asset (including harmonic signatures and power quality impacts) must be provided to the system operator so that it can be incorporated into their power system model to estimate the effects that the proposed interconnection will have on the system. If the system operator is not satisfied with the results of the model, the proposed interconnection will not be approved.

### **3 Perspectives of Second-life Battery Companies**

We interviewed eight SLB companies based in Canada and the United States to learn about their experience working in the emerging SLB industry. This section details what those companies shared with us regarding their product designs and market segment choices, as well as the regulatory, economic, and technical barriers they have encountered during development.

#### **3.1 Projects and use cases**

In general, ancillary service requests can only come from utility companies or electricity system operators, and are predominantly served by front-of-the-meter (FTM) energy assets. Our stakeholder research revealed that most North American SLB companies are focused solely on commercial and industrial customers and behind-the-meter (BTM) projects and therefore have not yet produced SLB systems that provide ancillary services.

The most common BTM energy storage services provided by the interviewed SLB companies were peak shaving, demand charge reduction, and backup power, with some companies also providing solar photovoltaic self-consumption, power factor correction, and transmission/distribution deferral for EV charging infrastructure. One of the SLB companies also offers a mobile BESS product. The eight SLB companies reported existing project sizes ranging from several hundred kWh to many tens of MWh, with future project sizes expected to grow into the hundreds of MWh in the coming years. Most of the SLB companies reported typical energy storage durations of 2 to 4 hours, mostly due to market demands, with two of the companies exploring durations as long as 12 to 14 hours.

Of the eight interviewed SLB companies, only one had completed an FTM project (a single at-scale prototype on the order of 50 MWh in the United States). This company is planning to use this system to provide ancillary services, but is presently focusing on energy arbitrage as an FTM energy service. The other SLB companies either exclusively sell BTM products to commercial and industrial customers, or have so far only built BTM pilot projects that serve their own facilities. Two such companies began by serving off-grid customers due to the ease of interconnection and certification. While these BTM-focused companies all expressed interest in building FTM systems in the future due to the significant economic potential of such systems, only one had foreseeable plans to enter that space, with a focus on energy arbitrage rather than ancillary services.

When asked why they were not pursuing FTM projects, most SLB companies expressed a hesitation to undertake the large-scale projects typical of the utility space, especially since many competitive new-build BESS solutions are already available at the utility scale. One interviewee described the transition from producing BTM systems to producing FTM systems as a “seismic shift” due to the larger BESS companies that compete at the utility scale. Two SLB companies also reported having conversations with utility companies in the United States who expressed reluctance to work with this undemonstrated technology and the small startup companies that make up most of the nascent SLB industry.

#### **3.2 System design**

Our conversations with SLB companies revealed a wide range of similarities and differences in how they design their SLB systems. The following subsections compare and contrast their various

methods and preferences regarding battery acquisition, system architecture, battery management, and thermal management.

### **3.2.1 Battery acquisition**

While third-party sourcing is occasionally utilized by some SLB companies, most of them agreed that it is preferable to source used EV batteries directly from OEMs, as this facilitates the collection of battery specifications and avoids the added cost and uncertainty that can accumulate through longer third-party supply chains. In some cases, the acquired EV batteries have been pre-screened by the OEM to ensure viability for second life, while in other cases, the SLB company must screen the batteries themselves after receipt. Most of the eight SLB companies source batteries from a single OEM, with very few instances of multiple SLB companies sourcing from the same OEM.

All of the interviewed SLB companies focus on selling products composed of EV batteries from a single EV model (rather than mixing different EV battery types within the same system), as this avoids added complexity and facilitates certification. However, some SLB companies foresee much larger systems being built in the future, which will likely require integration of multiple EV battery types based on available volumes. Interestingly, the SLB companies varied widely in their preference of repurposing EV battery modules vs full EV battery packs: some advocate for full-pack repurposing as the only economically viable pathway; some see more value in the customizability of working with separated modules; and some work with both packs and modules depending on the available supply.

### **3.2.2 System architecture**

Our stakeholder research also found significant variance in how SLB companies connect their battery units and power converters, with some companies opting for AC-coupled architectures and others opting for DC-coupled architectures. Two companies working at the module level both described architectures with multiple modules stacked in series to achieve a desired DC voltage. However, one of these companies applies DC-DC converters to each individual module to enable optimal power control when different modules are at different state of health (SOH) and state of charge (SOC) levels.

For pack-level systems, one company described an architecture with DC-DC converters applied to each individual pack, while another company built an AC-coupled pilot project with multiple DC strings each composed of two series-connected EV battery packs in order to double the DC voltage. In the latter case, the company also retrofitted contactors and fuses with higher voltage ratings since the original hardware was not designed for this higher voltage.

### **3.2.3 Battery management**

Repurposing an EV battery requires either accessing the OEM BMS or retrofitting a custom BMS. For SLB companies working at the module level, applying a custom BMS is sometimes the only option, since they often source separated modules without the OEM BMS attached. Also, damage can occur to electronics and sensory cables during disassembly. Companies working at the pack level are more likely to have a choice in whether to retrofit the BMS.

Five of the interviewed SLB companies stated that they retrofit a custom BMS in their systems, including some companies working at the pack level. This choice reportedly not only offers greater control flexibility, but also relieves the OEM from liability during second life. One SLB company

reported that their partner OEM prefers that the original BMS not be used in second life so that they do not have to provide support with BMS access and maintenance. In contrast, one SLB company working at the pack level described how they communicate with the OEM BMS without OEM support in order to avoid the cost and time requirements of opening the pack and retrofitting hardware.

Not all interviewed SLB companies described specific BMS topologies for managing cell-level voltages, but one company described a master-slave topology for their pack-level system design, while another company described a distributed topology for their module-level system design. These differences make sense since the master-slave topology is better suited for a relatively small number of units (e.g., 10 packs in a containerized product) while the distributed topology is better suited for a relatively large number of units (e.g., 400 modules in a containerized product).

### **3.2.4 Thermal management**

The interviewed SLB companies vary widely in their approach to thermal management. Only one of the companies exclusively relies on liquid cooling for their SLB products. Their pack-level product is designed for a 2 h rate, but they estimated that liquid cooling would be unnecessary at a 5 h rate or slower. They also noted that their liquid cooling capability would make it relatively easy for them to allow their existing system design to go to higher power levels for ancillary services. One company prefers to use the built-in liquid or air-based cooling capabilities of the EV batteries they receive, and has experience building both liquid-cooled and air-cooled systems.

One of the companies used liquid cooling in their first prototype, but moved to air-based cooling in their next generation after finding that liquid cooling overcomplicated their module-level product design and was ultimately unnecessary at their intended maximum 3 h rate. Similarly, one company used thermal cameras to verify that their full packs did not require liquid cooling at their intended 3 h rate, and therefore opted to not utilize the built-in liquid cooling capability of the packs. Another company working at the module level also opted to not utilize the built-in liquid cooling capability of their batteries for their intended 2 h rate, and expects to start sourcing air-cooled EV batteries in the future.

Finally, one of the SLB companies explained that they fundamentally prefer passive cooling over active cooling for their pack-level systems. They cited the Electric Power Research Institute's BESS Failure Incident Database, indicating that over 90% of recorded BESS incidents are related to the failure of an auxiliary system (e.g., liquid cooling system or fire suppression system). This SLB company therefore strives to eliminate as many auxiliary systems as possible, opting to place their repurposed batteries in an open-air field rather than a containerized solution with active cooling and fire suppression. This not only reduces failure points but also mitigates cost and complexity. This company also prefers use cases with lower power rates, which reduces the need for active cooling. In cooler environments when idle batteries would normally be heated by an active thermal management system, they can instead shuttle energy back and forth between their packs so that the packs can self-heat.

### **3.3 Regulatory challenges**

The most significant challenges identified by the interviewed SLB companies were related to regulations, especially the various UL certifications applicable to SLB systems. However, the degree to which these regulatory challenges are experienced can vary significantly for different SLB companies. The following subsections will summarize specific regulatory challenges described by the interviewees.

#### **3.3.1 UL 9540 and UL 1973 certifications**

Perhaps the greatest regulatory challenge identified by the SLB companies is the difficulty in achieving system-level UL 9540 certification, specifically due to its prerequisite for UL 1973 certification on the batteries. As described in Section 2.1, manufacturers of batteries intended for stationary applications must certify their batteries under UL 1973 so that those batteries can be deployed in certified BESS projects. Since UL 1973 does not apply to EV applications, EV batteries are not typically certified under UL 1973. This means that an SLB system cannot be certified under UL 9540 unless the SLB company achieves UL 1973 certification for the acquired EV batteries.

Since UL 1973 requires all OEM cell specifications (including material compositions), the certification often hinges on the willingness of OEMs to make this proprietary information available to SLB companies. Most of the interviewed SLB companies reported being unable to achieve UL 9540 certification for their product design because they did not have access to the necessary OEM cell specifications to meet the requirements of UL 1973. One of the SLB companies was able to work with specific OEM partners to meet the UL 1973 requirement, but without such partnerships, UL 9540 certification is very difficult for SLB companies to achieve, especially if repurposing at the pack level. Several of the interviewed SLB companies reported that they were able to meet every other requirement of UL 9540 (as well as large-scale fire testing as per UL 9540A), or at least meet every intent of the standard, but still could not get certified because of UL 1973 requirements. One SLB company shared that they sometimes don't even know who the OEM is when they acquire a used EV battery. Another interviewee shared that while EV battery OEMs could choose to certify their batteries under UL 1973 themselves in order to facilitate second life, they presently have no incentive to do so and would prefer to certify and sell stationary batteries and EV batteries separately.

Another complication with UL 9540 and UL 1973 is that certification can only be achieved for one specific battery design at a time. An additional round of certification will be required if there is any change in the design characteristics of cells, modules, or packs used in an SLB product, even if using different models of the same EV battery. This forces SLB companies to limit themselves to repurposing a small number of specific EV battery types or otherwise accept significant certification costs in order to diversify their EV battery sources. The added cost of redoing large-scale fire testing according to UL 9540A is especially prohibitive since each certification requires the thermal-event testing of an entire BESS product. One SLB company that has achieved UL 9540 certification for a single EV battery type explained that they strived to certify a fundamental, battery-agnostic architecture in hopes that the introduction of different battery types in the future can be handled with amendments to the existing certification instead of requiring a complete recertification process every time. The recertification issue is not something that new-build BESS companies would typically have to deal with, as they generally produce a single consistent battery type instead of acquiring multiple battery types from various sources.

### **3.3.2 UL 1974 certification**

Another major regulatory challenge is UL 1974 certification for the SLB manufacturing process, which applies exclusively to SLB companies and not to new-build BESS companies. As of January 2026, only three of the eight interviewed SLB companies had achieved UL 1974 certification for their SLB manufacturing facilities. These companies will still have to update their documentation as part of the UL 1974 certification each time they introduce a new EV battery type into their manufacturing line. Some SLB companies reported significant struggles in trying to achieve UL 1974 certification, describing some of the certification requirements and test procedures as impractical, uneconomical, redundant, and ambiguous.

One reported issue is that UL 1974 requires cell and pack specifications directly from the OEM, similar to the UL 1973 issue described in Section 3.3.1. One SLB company shared that many OEMs either do not possess certain required specifications (e.g., “calendar expiration date”), refuse to share proprietary information with SLB companies or NRTLs, or require many months to navigate legal procedures before proprietary information can be shared. The same SLB company argued that the UL 1974 testing and safety requirements are already rigorous enough that OEM specifications should not be necessary for SLB certification. The interviewed SLB companies who have achieved UL 1974 certification also have direct relationships with OEMs, which typically makes it easier to meet these certification requirements.

Another reported issue is the nature of the UL 1974 testing requirements. Some SLB companies found certain test procedures to be academic and impractical, requiring unnecessarily long test durations to obtain the desired information about battery health and safety (up to 40 hours or more for all required tests). Furthermore, repurposing below the pack level requires testing to be carried out on each individual cell, which leads to even longer overall test durations. One SLB company also found some testing requirements to be poorly defined, with three different inspection/certification groups interpreting the requirements in three different ways, leading to very different test durations. Despite these reported issues, UL 1974 certification has been achieved for repurposing at both module and pack levels.

### **3.3.3 Local permitting**

As described in Section 2.2, final permitting for BESS projects rests with local AHJs. Some of the interviewed SLB companies lacking UL certifications reported that AHJs can be very critical of their project designs, with one SLB company sharing that local fire departments often request expensive project modifications even when the project already complies with the applicable fire code. On the other hand, one SLB company with UL certifications reported productive interactions with AHJs. In their experience, AHJs don’t have official added safety requirements for SLBs, but rather engage in ad hoc discussions to confirm that the SLB system meets all the same safety standards as a new-build BESS. To instill confidence, this SLB company elects to provide AHJs with additional documentation to make it abundantly clear that the battery has already operated safely for many years in EV service, has passed its infant mortality, and has been thoroughly tested for performance and safety in second life. This same SLB company has also found that most fire chiefs are apprehensive about batteries in general, and are not familiar enough with battery technologies to be more critical of SLBs than new-build BESS. Instead, the fire chiefs just recognize that lithium-ion batteries are being installed and expect the project developer to demonstrate that the system is safe.

Only one interviewed SLB company had experience with getting approvals specific to ancillary services. For their FTM system in the United States, the electricity system operator required them to complete three tests before the SLB system would be approved to provide ancillary services: 1) discharge for 1 hour at full power; 2) provide reactive power; 3) fast ramp to full power. The interviewee considered the fast-ramp test to be the most challenging due to advanced software control requirements. Note that these same tests would also be required of a new-build BESS.

One SLB company identified a separate permitting issue related to in-house testing. Since their facility lacks an interconnection agreement allowing for electrical discharge into the grid, they are unable to run in-house tests that would assess SLB performance in ancillary services. This creates a barrier to entering ancillary service markets since the SLB company cannot take the first step of investigating the potential without contracting external research partners.

### **3.3.4 Alternative pathways**

Failure to achieve UL certification does not necessarily mean that an SLB company cannot operate. One alternative is site specific certification. Due to the various obstacles encountered with UL certifications, one of the interviewed SLB companies shared that they were instead exploring options to achieve BESS field certification under special inspection SPE 1000. However, the NRTLs they spoke with did not feel confident about certifying a BESS composed of uncertified batteries.

Another alternative is to intentionally target project locations where local AHJs are less strict. As mentioned in Section 2.2.1, some AHJs may use their discretion and allow a project developer to provide sufficient documentation demonstrating safety in lieu of official certifications. This is especially relevant for pilot-scale SLB demonstration projects with relatively short operating periods. This is also a major reason why many SLB companies have focused solely on BTM, off-grid, or mobile projects: compared to large-scale FTM projects, these smaller-scale projects are much more likely to gain permitting approval from risk-tolerant local AHJs when the SLB product lacks official certifications. However, the interviewed SLB companies also recognized that reliance on AHJ subjectivity does not make for a scalable business model. Growing an SLB business in North America will ultimately require official product certifications.

The final alternative pathway is to focus on overseas markets instead of North American markets, as they often have less strict regulatory processes or certification requirements. One interviewee shared their knowledge of Asian and African markets, which do not have the SLB regulatory frameworks that exist in North America. This lack of regulation allows small SLB companies to develop many different kinds of SLB projects, even in the residential sector. While BESS safety is still a top concern in these markets, used EV batteries that have seen 5 to 10 years of EV service are generally viewed as safe since they have proven to have no major manufacturing defects. As long as an SLB company can test and validate quality SLB products, they have the opportunity to innovate, develop a strong safety reputation, and earn the confidence of customers and stakeholders without being bound by official safety certification requirements.

The same interviewee also shared information that up to 60,000 retired or damaged EVs are being shipped out of North America every year – largely to Asian markets where companies will refurbish, remanufacture, or repurpose the vehicles and/or batteries. The reduced regulation in the Asian

markets allows automakers in North America (where extended producer responsibility legislation is still lacking) to unburden themselves of end-of-life EVs while still fulfilling sustainability expectations, since the shipped vehicle and/or battery can still provide carbon reduction benefits overseas. This means that SLB companies can more easily repurpose North American EV batteries by building SLB projects in overseas markets with reduced regulations. However, nearly all of the interviewed SLB companies were focused on building projects in the United States and/or Canada, with the only exception being a new startup venture planning an off-grid pilot project in Mexico. Despite the lack of extended producer responsibility legislation, one SLB company reported that automakers are still keen to secure sustainable pathways for used EV batteries within North America, which bodes well for SLB companies.

### **3.3.5 Revision of UL certification standards**

The most viable solution for overcoming the biggest regulatory barriers is already underway. Rather than expecting SLB companies to innovate their way over these barriers, UL has recognized that their certification standards must be revised to properly accommodate SLB technologies so that the SLB industry can grow to meet the rising demand for BESS and the rising supply of used EV batteries. Most of the interviewed SLB companies have been participating in task groups to propose revisions to UL 9540, UL 1973, and UL 1974. These task groups are planning to submit proposals to the corresponding UL technical committees for each of these standards in 2026.

The UL 9540 task group is largely focused on developing proposed revisions to UL 1973 so that SLB companies can meet the UL 1973 requirements and thereby remove the major barrier to UL 9540 certification. Their approach is to propose an alternative UL1973 pathway via an annex that outlines a set of requirements for the specific case of SLBs. There is a precedent for this approach: a UL 1973 annex was previously added to cover the case of lead-acid batteries, since UL 1973 is geared towards lithium-ion technology which is fundamentally different from lead-acid technology.

The intention of the proposed SLB annex is to demonstrate equivalencies between UL 1973 and comparable standards applied to EV batteries. Several of the interviewed SLB companies contended that EV batteries are arguably safer than stationary batteries since EV batteries are designed for more extreme scenarios (e.g., vehicle collision or submersion) according to the rigorous SAE industry standards outlined in Section 2.1.2. Since the intent of SAE standards are largely the same as the intent of the UL 1973 requirements, equivalencies can be drawn to demonstrate that new EV batteries do meet the intent of UL 1973.

With established equivalencies, the burden on SLB companies is then to carry out the minimum required testing to demonstrate that a used EV battery is still safe enough to use in second life. On this point, some of the interviewed SLB companies contended that the required system-level fire testing specified by UL 9540A should already be sufficient to demonstrate that an SLB system is safe, and additional battery-level abuse testing under UL 1973 should therefore not be required for SLBs. To support this argument, one interviewee pointed out the NFPA standards (which require UL 9540 certification) already include equivalency provisions that allow project developers to deploy products that feature “equivalent means of protection” that fulfill the intent of the standard.

The UL 9540 task group is also considering how to revise UL 9540 so that it is less burdensome for an SLB company to deploy different EV battery types in a BESS product. The UL 1974 task group is working to revise UL 1974 with industry input to ensure that battery repurposing processes are economically viable and scalable.

We also spoke with representatives from UL to get their perspectives on how their standards might evolve in the coming years to help remove barriers for the SLB industry. For UL 1974, there is a potential for certain tests to be waived for a portion of batteries in a given repurposing facility when large volumes are being repurposed, though some tests (e.g., open-circuit voltage, galvanic isolation) are considered essential for every repurposed battery unit. There is also a potential for numerical methods to be used to estimate battery capacity based on a partial discharge test rather than a full capacity test. For UL 1973, there is a potential for additional testing to cover certain battery construction requirements (e.g., critical components that are not typically UL certified in EV batteries). There is also a potential for EV manufacturers to be required to certify their batteries to UL 1973.

### **3.4 Economic challenges**

As a relatively new branch of a competitive energy storage sector, economic considerations are crucial for the SLB industry. The following subsections detail the main economic challenges that came up in our conversations with SLB companies.

#### **3.4.1 Competition with new batteries**

A common sentiment expressed by the interviewed SLB companies is that one of their greatest challenges is competing with the pricing, scale, maturity, and energy density of new-build BESS projects. As explained in Section 3.1, this challenge is a primary reason why very few SLB companies have entered the ancillary service market, which is embedded in the risk-averse utility sector where manufacturing scale and technological maturity are especially favoured. Low-cost lithium iron phosphate (LFP) technologies, especially from Asian BESS suppliers, reportedly make up some of the toughest competition.

While some of the interviewed SLB companies stated that their products are already cost competitive, some newer companies reported struggling to compete in requests for proposal (RFPs) where large, established BESS companies have a considerable advantage, including RFPs issued by government departments. One such company expressed that if governments want to support the growth of the SLB industry, they should explore ways to “level the playing field” on relatively low-risk RFPs (e.g., remote project sites) so that SLB startups can demonstrate a more sustainable BESS solution even if their price point has not yet achieved scale.

#### **3.4.2 Battery supply chains**

One major factor in the cost competitiveness of SLB projects is the sourcing of used EV batteries, which presents its own economic challenges. One consideration is that sourced batteries must be of sufficient SOH for repurposing, and if batteries are not pre-screened by the supplier, then there is a risk of acquiring a used EV battery only to find that it cannot be repurposed. However, none of the interviewed SLB companies raised this point as a significant economic challenge in their experience

to date. The greater challenge is the cost of battery acquisition. As one SLB company explained, third-party supply chains often feature relatively high prices from marketplace resellers striving to turn a profit on the used EV batteries they acquire, while contracting directly with OEMs tends to secure lower prices. The latter option comes with the trade-off of requiring more upfront work to establish a long-term supply contract with a large company.

Since it is critical for SLB companies to compete economically with new-build BESS projects, some of the interviewees expressed a preference for direct OEM supply chains in order to minimize costs. On the other hand, some SLB companies planning for utility-scale projects shared that they expect to collect used EV batteries from many different sources in order to amass their desired battery volumes. One company described how a more widespread network of centralized EV battery collection and distribution hubs could help streamline third-party supply chains and reduce barriers to entry for SLB startup companies who lack formal OEM partnerships.

One interviewee also suggested that governments can help build up local SLB supply chains by restricting EV OEMs from repatriating their used batteries to the countries of origin, thereby retaining batteries in the country in which the EVs were sold. This would not only support the SLB industry, but also generate an important feedstock of battery materials that can eventually be recycled into local battery manufacturing industries. However, the interviewee noted that some major EV OEMs are firmly opposed to this concept as they want to retain the value chain themselves.

### **3.4.3 Regulatory impacts**

The current SLB regulatory environment also creates significant economic barriers for SLB companies. Several of the interviewed SLB companies emphasized that excessive compliance testing will make it very difficult to sell SLB products at prices that can compete with new-build BESS products, which undermines the SLB business case. As mentioned in Section 3.3, the requirement to repeat expensive testing and certification processes for every unique EV battery type deployed in a given SLB product is especially burdensome both logistically and economically. One SLB company estimated a total cost of \$1.2 million USD to achieve a single set of certifications under UL 1974, UL 1973, and UL 9540 with UL 9540A fire testing.

The regulatory burden also puts greater pressure on SLB companies to establish a reliable supply (ideally through a long-term contract with an OEM) of whichever EV battery type they have achieved certification for, since they have already invested considerable capital into certifying their products for that specific battery type. A shortage of that specific battery type would force the SLB company to start sourcing different battery types, which would then require even more investment in retesting and recertification. The necessity of working closely with OEMs to access the cell specifications required by current UL standards also favours the direct OEM supply chain model over third-party supply chains that cannot provide OEM specifications. The current regulatory framework therefore pushes SLB companies toward the direct OEM supply chain model regardless of whether it is the best fit for their business model and project plans.

### **3.4.4 Product warranty**

Another economic challenge expressed by the interviewed SLB companies is competing with the 20+ year warranties typically offered for new-build BESS projects. Since SLBs are degraded in capacity

compared to new batteries, SLBs will generally not last 20 years. Four of the interviewed SLB companies had already established product warranties, and all four were reported to be in the range of 10 to 15 years.

The shorter warranty period of SLB products is generally accounted for in the system pricing, which makes the offer acceptable to customers. Since non-battery components of the system will generally last 20 years or more, some SLB companies also offer an option for customers to double the system life beyond its original warranty period by buying replacement batteries. For SLB systems, the batteries are a relatively inexpensive component, which makes the extension purchase a potentially attractive option. Of course, a replacement relies on the SLB company still being in business in 10+ years.

The structure of the warranties can take slightly different forms. For example, one company offers a 15-year power guarantee, while another company guarantees a 10-year system life and a 3% annual degradation rate. Commonly, a service agreement establishes that the SLB company will replace the installed batteries if necessary to ensure the system fulfills the warranty period (contingent on the customer adhering to defined operational limits such as a power envelope and temperature range). This means that SLB systems must be designed so that the batteries are easily replaceable.

Part of the challenge for SLB companies is the added degree of uncertainty around whether their product will really last for the entire warranty period without a battery replacement. The degradation rate of SLBs is typically less predictable than that of new batteries, which means SLB companies must take extra care with respect to product warranty. One of the interviewed SLB companies explained how they closely monitor the long-term performance of their installed systems, and adjust the depth of discharge based on whether the observed degradation rate is faster or slower than predicted. This helps to ensure that the warranty period is fulfilled without significantly impacting real-time performance.

### **3.4.5 Project financing and insurance**

Some of the interviewed SLB companies also identified economic barriers related to financing and insuring SLB projects. While this is less of an issue for smaller-scale BTM projects, larger-scale FTM projects typically cannot be undertaken without parties willing to finance and insure the project. One SLB company described the lack of SLB financing frameworks as a major barrier for deploying SLBs in ancillary services. Another SLB company shared that they are still working on bankability for their utility-scale project plans, which would then translate into insurability.

### **3.4.6 Research and investment**

One SLB company reported difficulties in building a strong case to attract investment in an exploratory SLB business model, despite expressed interest from EV OEMs. The SLB company cited a lack of published research that could support the business model with quantifiable data. This issue highlights opportunities to foster more partnerships between SLB companies and research institutions, which could be supported by government funding.

## **3.5 Technical challenges**

Beyond regulation and economics, the technological nature of SLBs makes them inherently more complex to work with than new-build BESS. The following subsections describe the main technical challenges that the SLB companies shared with us.

### **3.5.1 Variance in battery design**

Some of the interviewed SLB companies shared how the significant variations among EV battery designs complicates the SLB product design process. Whereas a new-build BESS can be designed around a consistent supply of batteries and other system components, SLB companies often do not have that luxury. For example, a custom BMS designed for one EV battery type may not work with another, or a safety system originally designed for one lithium-ion chemistry may no longer comply with safety standards if a different chemistry is deployed later (different chemistries have different safety hazards and thus require different safety features in a BESS). They added that the differences in safety standards for different chemistries makes it very difficult to combine different EV battery types into one system. They explained further that because EV battery technologies are evolving so quickly, it is difficult to develop a single generalized design that can accommodate any EV battery type. They said that it can take two years to fully demonstrate a product and prove that it is working, by which time the available EV battery technology has changed and certain aspects of system design need to be revised to accommodate these changes. Even for a given EV battery type, they have found that battery OEMs make incremental design changes often, such that a battery from one model year cannot necessarily be paired with the same battery type from a different model year. Another SLB company shared that this continual design iteration makes it difficult to source some EV battery components, as their original production may be obsolete with only the OEM holding the remaining supply.

Some SLB companies are already innovating to overcome the challenge of EV battery design variance. Two of the interviewed SLB companies have strategically designed their products to be battery agnostic so that they can accommodate any EV battery type. The key features of these battery-agnostic designs is a granular power conversion architecture allowing for dispatch and control of individual packs or modules. These companies recognize that utility-scale SLB projects will require tens of thousands of used EV batteries, making it unlikely that a single EV battery type can be deployed across the entire system. The battery-agnostic design approach makes these utility-scale projects more achievable for SLBs.

### **3.5.2 Variance in battery degradation**

Another challenge that SLB companies have encountered is the reality that large battery packs do not degrade uniformly. For a new-build BESS, all cells start off at 100 % SOH and can therefore be controlled in bulk. For used EV batteries acquired by SLB companies, there will be a spread of SOH levels among different battery packs, different modules within a given pack, and different cells within a given module. One way of addressing this issue is by testing, grading, and sorting battery units (i.e., packs, modules, or cells depending on the chosen repurposing level) so that SLB systems can be built out of battery units with similar SOH levels. Such testing, grading, and sorting procedures are required for UL 1974 certification, as described in Section 2.1.4.

Further complicating this matter is the fact that two EV battery units with the same present-value SOH may have been operated differently during first-life operation in EV service, which would increase the likelihood that they will degrade at different rates in second life. This is an issue since an SLB company may not know the usage history of an acquired EV battery, especially if the OEM BMS is not accessible. If the usage history is accessible, diagnostic tools can be used to establish a more robust understanding of how a battery will perform in second life, and at least one of the interviewed SLB companies has developed such tools. In Europe, mandated battery passports will help to make usage histories more accessible to SLB companies and other stakeholders, but there are currently no such mandates in North America. As another means of addressing degradation variance in acquired EV batteries, one of the interviewed SLB companies applies a specialized method to align the SOH of acquired battery units using power throughput before the battery units are repurposed into an SLB system.

Even if a full set of battery units are essentially identical when repurposed into an SLB system, there is still no guarantee that they will continue to degrade at the same rate in second life. This can potentially lead to weaker units eventually limiting the performance and life of the entire system. To fully address this issue, operational control must be exerted over individual battery units so that weaker units can be operated more conservatively. This is another benefit touted by the SLB companies who employ a granular power conversion architecture. Just as it provides a battery-agnostic solution to address the issue of battery design variance, it also provides an SOH-agnostic solution to address the issue of battery degradation variance. In these designs, the smaller the battery unit, the finer the level of granular control, and the more optimized the system performance can be.

Another technical challenge stemming from battery degradation variance is when an acquired EV battery has one or more failed cells. One of the interviewed SLB companies raised the point that since individual cells usually aren't serviceable in an EV battery, a single failed cell often means the entire module cannot be used in second life. Different EV battery designs may feature dozens of modules, or as few as four modules, meaning that a single failed cell can render 25 % of the pack unusable. If the SLB company is repurposing at the module level, then the remaining modules can still be salvaged and repurposed. But if the SLB company is repurposing at the pack level, then they must choose to either discard the entire pack or modify the pack so that it can be operated without the failed module (such as retrofitting cables to jumper over the unusable module). The interviewee expressed concerns about the pack modification option, since any modification further complicates the repurposing process and raises additional questions when seeking certification. This interviewee felt that the most streamlined route to certification is to maintain the original pack design as much as possible.

### **3.5.3 Thermal management and safety**

Recent research from Sandia National Laboratories [69-71] investigated how the safety profile of lithium-ion batteries changes as the batteries age, assessing how different degradation mechanisms impact two key safety metrics: 1) the onset of failure and 2) the magnitude of the failure response. The researchers concluded that lithium plating in particular can lower the onset of thermal runaway and potentially also increase the heat response during failure. This is an important finding for the thermal management and safety of SLB systems, as SLB companies may need to place more emphasis

on maintaining ideal temperature ranges compared to new-build BESS depending on the severity and type of degradation.

As outlined in Section 3.2.4, there is no consensus among SLB companies when it comes to SLB thermal management systems, with some preferring liquid-based methods, some preferring air-based methods, and some being impartial. Several of the interviewed SLB companies described the implementation of liquid-based methods as technically challenging and not worth the effort, increased design complexity, and added failure points, especially when the battery is only running at 3 h power rates. As mentioned in Section 3.2.4, public data indicates that most BESS failures are attributable to failed auxiliary systems such as cooling units. On the other hand, one SLB company felt that their liquid-cooled design made their product more adaptable to the higher power rates often associated with ancillary services. Another company indicated that they would switch to liquid cooling if they were developing a product for higher power applications than the relatively low power rates they are currently designing for. Whatever choice an SLB company makes for thermal management, the SLB system should be operated in a way that minimizes safety risks such as thermal runaway. For liquid-based systems, this may mean consuming more auxiliary power than a new-build BESS would require in order to maintain a narrower battery temperature range. For air-based cooling systems, this may mean operating the battery more conservatively than a new-build BESS so that battery temperatures do not rise as high.

Ideally, an SLB company would be able to continually analyze the usage history of individual battery units during second life, monitor signs of lithium plating, and operate any higher-risk battery units more conservatively to accommodate a decreasing thermal runaway onset temperature. This would avoid needlessly throttling low-risk battery units, and thereby co-optimize the safety and performance of the SLB system as a whole. Once again, this highlights the value of monitoring and controlling SLB systems at the level of individual battery units with a granular power conversion architecture. Two of the interviewed SLB companies with a granular design explained how they can identify and throttle individual battery units that are degrading quickly or exhibiting safety risks such as lithium plating or torn cell tabs resulting from manufacturing defects. Their ability to dynamically adjust at this level avoids having to de-rate an entire system or prematurely discard at-risk battery units.

Another important consideration is the placement of the battery temperature sensors in an SLB system. This is especially important if the SLB company is relying on OEM temperature sensors, but has modified or even shut down the OEM thermal management system. For example, a sensor may be placed along a coolant pipe; but if the coolant is no longer circulating, it would give erroneous results. One of the interviewed SLB companies expressed concerns about having no control over where the OEM temperature sensors are placed within EV batteries, reporting that they had to remove the battery pack cover, place a thermal camera above the pack, and run battery tests with the thermal camera running in order to feel confident that the battery was safe to operate in their intended application without liquid cooling. Without such verification studies, SLB companies may need to be conservative in how they interpret temperatures being read from OEM sensors in a second-life application.

### 3.5.4 Battery performance limitations

The performance of SLBs is inherently limited compared to new batteries, due to capacity degradation, internal resistance growth, and potentially restricting operations to enhance safety. To account for these battery performance limitations, SLB companies must develop operational control strategies that balance real-time performance with safety, lifetime and cost.

As explained in Section 3.5.3, the possibility of SLB systems exhibiting decreased thermal runaway onset temperatures and underestimated temperature measurements gives SLB companies an incentive to apply narrower operational temperature limits than might be applied to a comparable new-build BESS. Maintaining ideal temperature ranges also helps to slow degradation and thereby prolong the life of the SLB system. Three of the interviewed SLB companies reported intentionally applying a more conservative upper temperature limit, while one newer company reported relying on OEM recommendations as they develop their control strategies.

Another way to accommodate the performance limitations of SLBs compared to new-build BESS is to narrow the operational SOC window as a means of slowing the degradation rate. Most of the interviewed SLB companies reported limiting the SOC at least somewhat on both discharge and charge, but their approaches varied considerably. Some companies apply SOC limits similar to what is typical in EV applications, such as 5 % to 95 % SOC, while one company reported that their partner OEM recommends a 70 % depth of discharge when operating their EV batteries in second life. Two other companies working with multiple EV battery types reported that while they generally use a smaller depth of discharge compared to first-life batteries, they tailor their specific SOC limits and other operational parameters to each given battery type, since different chemistries sometimes have different SOC ranges that they want to avoid. One company reported that by using more conservative temperature and SOC limits compared to EV applications, their SLB product exhibits a 2-3 % annual degradation rate compared to the 4-5 % figure common to that same battery type during EV service.

Generally, applying narrower temperature and SOC limits results in an SLB system with lower energy and power capabilities. To counteract this, SLB systems can be intentionally oversized by installing more battery units than what is necessary to meet the required energy and power capabilities of the system. The more oversized the system is in terms of real battery capacity, the less energy and power is needed from each individual battery unit (the balance of plant can remain as requested, and not be oversized). Two of the interviewed SLB companies stated that they intentionally oversize their SLB systems so that individual battery units can operate within narrower temperature and SOC limits to extend their life. The degree of oversizing is ultimately a matter of optimizing the lifetime economic value of the system, where more upfront oversizing costs result in longer operational life.

One of the interviewed SLB companies indicated that their granular power conversion architecture mitigates the necessity of applying system-wide limitations on temperature and SOC. They apply the same temperature and SOC limits that would be used in EV applications, and instead rely on granular monitoring and control capabilities to reduce the strain on individual battery units as necessary. This company further explained that even though many ancillary services do not require a significant depth of discharge, there is a lot at stake with ancillary services and it is therefore preferred to make as much capacity available as possible for a given BESS. Their architecture allows them to utilize the maximum capability of each individual battery unit and the system as a whole.

### **3.5.5 Monitoring and control systems**

The previous four subsections have made it clear that monitoring and control is critical for SLB systems. However, monitoring and control systems present their own unique technical challenges for SLB companies. On the monitoring side, SLB companies have to either work with OEMs to access and program the OEM BMS, develop their own custom methods to access and program the OEM BMS, purchase a third-party BMS, or design and produce their own custom BMS. All four of these options are challenging: working with an OEM can take a lot of time and effort just to be able to use a BMS that works with one specific EV battery type; accessing an OEM BMS without the support of an OEM requires the development of custom interfacing tools, and can potentially have legal ramifications; a third-party BMS still requires labour, time, and cost to connect to the battery, and procedures will differ for different EV battery types; in-house development requires significant investment.

The available BMS options may also depend on the acquired EV battery type as well as the chosen SLB business model. One of the interviewed SLB companies receives used EV battery modules directly from an OEM without receiving any BMS hardware, and therefore has no choice but to develop cell voltage harnesses and establish communication between the modules and a third-party BMS. Similarly, another SLB company works with an OEM that explicitly prefers the OEM BMS not be used in second-life. Another SLB company prefers to repurpose unaltered EV battery packs to minimize costs, but with no BMS support offered by from the OEM, had no choice but to develop custom methods to access the OEM BMS. Two other SLB companies have had to develop proprietary BMS technologies in order to enable the battery-agnostic system designs that their business models are centred around. These differences illustrate the challenging pathways that SLB companies must navigate when entering the industry, working with new OEMs, or developing new products.

On the control side, SLB companies must develop a power conversion architecture and a control strategy, both of which require many consequential decisions impacting the cost, performance, lifetime, and safety of the SLB system, as well as the flexibility to accommodate different EV battery types in the future for system augmentation purposes. These decisions are especially challenging for SLBs given the significant variance among used EV batteries in terms of design, performance, and degradation. Two of the interviewed SLB companies seem to be making strides in developing battery-agnostic control systems that utilize granular power conversion architecture combined with proprietary BMS technology to control and optimize individual battery units. One of these companies explained that their system design is a big reason why utilities are interested in working with them on ancillary service projects, since the more granular monitoring and control capabilities address many of the shortcomings of SLBs. The resulting SLB product is also flexible enough to accommodate the various types of ancillary service applications.

### **3.6 Advantages of second-life batteries**

While SLBs come with numerous regulatory, economic, and technical challenges, our conversations with SLB companies also highlighted several aspects of the SLB industry that are uniquely advantageous for electricity grid energy storage projects. This section will review six areas where SLBs can offer important advantages over new-build BESS.

### **3.6.1 Manufacturing standards**

Several of the interviewed SLB companies argued that EV batteries are inherently safer than stationary batteries since they must be manufactured to meet stricter safety standards applied to automotive applications. These standards were described in Section 2.1.2 and include FMVSS 305 crash testing, SAE J2464 abuse testing, and IP67 sealing.

### **3.6.2 Infant mortality**

Any manufactured product is more likely to have instances of defect-related failures early in product life, and the same concept applies to batteries. Several of the interviewed SLB companies raised the point that EV batteries that have been on the road for 1+ years have already passed infant mortality. This means that SLB systems have an inherently lower risk of defect-related battery failures than a new-build BESS. Other system components like power converters will have equal risk of infant mortality in both SLB systems and new-build BESS.

### **3.6.3 Power capability**

Batteries can be designed for high energy density or high power density. One of the interviewed SLB companies pointed out that while EV batteries are designed for high energy density to maximize driving range, hybrid EV batteries are generally designed for high power density so that a relatively small battery can still handle vehicle acceleration and regenerative braking. Power-dense batteries are better suited for high-power electricity grid applications such as ancillary services, but they also tend to be more expensive. The interviewee suggested that used hybrid EV batteries could be repurposed specifically for ancillary service projects at a significant discount, thereby offering SLB performance and/or cost advantages over a new-build BESS in ancillary services. It is worth noting however that future volumes of used hybrid EV batteries will be small compared to used EV batteries.

### **3.6.4 Control optimization**

The significant variance in EV battery design, performance, and degradation has driven some SLB companies to innovate and build SLB systems that can integrate and optimize any EV battery type. By using advanced BMS technology and a granular power conversion architecture, these companies can monitor and control individual battery packs or modules to co-optimize the performance, lifetime, and safety of every battery unit in the system. These innovations go beyond what is necessary and cost-effective for a new-build BESS with uniform battery units, but as a new-build BESS degrades throughout its life, the lack of granular optimization may cause the BESS to underperform compared to an optimized SLB system that has been running just as long. While this scenario is currently hypothetical, it demonstrates how the challenges of SLBs can be transformed into advantages through innovation.

### **3.6.5 Battery replacement**

Since SLB systems have to be sold with shorter warranties than new-build BESS, SLB companies have had to adapt to stay economically competitive. As a result, many SLB projects are designed for easy battery replacement in anticipation that batteries will be replaced during the life of the system. Even when the SLB system fulfills its 10 to 15 year warranty period, some SLB companies allow customers to buy replacement batteries so that the system lasts as long as the non-battery components (at least

20 to 25 years). The relatively low cost of used EV batteries combined with an ease-of-replacement design strategy means that it would be much more cost effective to extend the life of an SLB system than a new-build BESS, which is typically warrantied for 20 to 25 years anyway. While the economics will vary from case to case, an SLB system could potentially last longer than a new-build BESS at a lower cost.

### **3.6.6 Market entry points**

Repurposing is typically considered as one of several progressive stages in the EV battery life cycle, including manufacturing, first-life in EV service, reuse in EV service, refurbishment or remanufacturing for EV service, repurposing for BESS service, and recycling. One of the interviewed SLB companies also specializes in remanufacturing, working closely with various EV OEMs. They pointed out that there are other opportunities for EV batteries to provide BESS services before they are officially repurposed for second life, and they weren't referring to vehicle-to-grid technology.

In their dealings with EV OEMs, this SLB company has garnered interest in a warehousing business model where EV batteries can effectively be operated as BESS while they sit idle in storage before or after remanufacturing. The batteries would undergo only light cycling to offset the warehousing costs without incurring significant degradation. They also explained that due to the current surplus of manufactured EV batteries in the automotive industry, there could also be an opportunity for a similar model when EV batteries serve as BESS while awaiting first installation in an EV after initial manufacturing ("zeroth life"). While this model is currently only a concept, it demonstrates how the nature of the EV battery life cycle is itself an advantage over new-build BESS, with numerous low-cost opportunities to extract value from existing EV batteries for the benefit of the electricity grid.

## 4 Perspectives of Canadian Utilities and System Operators

We interviewed three Canadian electrical utility companies and two Canadian independent electricity system operators to inquire about the prospects, requirements, and perceptions of SLBs as a new technological solution for BESS. This section summarizes what we learned from these five entities, which we will hereafter refer to collectively as “grid operators” for brevity.

### 4.1 Opportunities for battery energy storage

Our conversations with grid operators highlighted a range of energy storage demands that SLBs can help serve, though these opportunities can vary significantly by jurisdiction. For example, one interviewee cited a 2026 Annual Planning Outlook report [72] in framing current and future opportunities for BESS in Ontario. We learned that Ontario’s installed energy storage capacity already leads Canadian provinces and is expected to reach 3000 MW by 2028 to help support Ontario’s anticipated growth in electricity demand. We also learned that due to the growing number of large, fast-ramping loads (e.g., data centres) seeking grid connection in Ontario, the provincial demand for ancillary services is also growing, with frequency regulation needs expected to grow from 100 MW in 2026 to 200 MW by 2030. Despite rising demands for ancillary services, various grid operators seem to agree that energy services such as arbitrage and peak shaving offer stronger economics for BESS than ancillary services alone. This means that BESS are best positioned to perform ancillary services if they are stacked with energy services, and the same concept applies to SLBs. While SLBs can also participate in Ontario’s operating reserve market, grid operators seem to agree that the opportunities for SLBs in this market are diminishing due to market saturation with large new-build BESS.

In contrast, we learned that Nova Scotia’s geography and lack of large hydroelectric and nuclear power plants means that meeting its 80 % renewable energy target will require heavy dependence on inverter-based resources such as wind, solar, and the high-voltage DC interconnection with the Maritime Link. To ensure grid reliability with this resource outlook as coal plants are retired, new generating assets built in Nova Scotia are required to support their own point of interconnection with ancillary service capabilities. This requirement, combined with planned fast-acting combustion turbines and a new transmission-line to the main North American grid via New Brunswick, means that there will not be much of a market for ancillary services in Nova Scotia. The main exception is reactive power services to ensure voltage stability, and three new 50 MW, 200 MWh BESS facilities in Nova Scotia are expected to help provide this service. However, voltage support services will also be provided by new synchronous condenser installations. New BESS capacity in Nova Scotia will primarily provide energy arbitrage of curtailed wind energy as well as utility peak shaving services.

We also learned about a range of other BESS applications in Canada. One utility described programs to improve electricity reliability in rural communities by installing small-scale BTM BESS (10 kW, 27 kWh) in rural homes at no charge to homeowners, as well as utility-scale FTM BESS (approximately 2 MW, 4 MWh) on the associated distribution feeders. The residential BESS are controlled by the utility to provide backup power during outages, but can be called upon by the utility to provide demand response and peak shaving when backup power is not needed. The utility-scale BESS allows for microgrid islanding during outages, but can be called upon by the utility to provide peak shaving and voltage support, and also to participate in the provincial electricity market. Another

utility described a self-consumption rebate program for residences and small-to-medium businesses with solar generation and/or BESS, as well as an incentive program for BESS that connect to the utility's distributed energy resource management system (DERMS) platform to allow the utility to call upon the BESS for peak shaving. These different programs demonstrate how some grid operators incentivize energy storage adoption for the benefit of the electricity grid.

A number of SLB companies, utilities, and system operators agreed that BESS will typically be sized for applications like energy arbitrage and peak shaving (usually less than 1 h power rate), and provide ancillary services as a stacked revenue stream. Several interviewees noted that the rapidly accelerating construction of data centres for artificial intelligence and cryptocurrency is also creating demand for fast-ramping, high-power energy storage. This presents a profitable revenue stream for BESS designs that are more in line with high-power ancillary service requirements, meaning that ancillary services could potentially be stacked more profitably in high-power datacentre applications than in lower-power energy arbitrage or peak shaving use cases.

## **4.2 Interconnection considerations**

As described in Section 2.2.2, a BESS will not be approved for grid interconnection unless it both complies with jurisdictional interconnection requirements and passes the grid operator's power system modelling test. The modelling requirements for grid interconnection mean that an SLB company must be able to produce a detailed model of how their SLB products will interact with the grid, down to an electromagnetic level. One potential challenge for SLB companies is acquiring the necessary battery specifications to produce such a detailed model when the OEM may not be supportive or even known. Furthermore, utility-scale SLB systems are more likely to include an array of different battery chemistries, voltages, SOH levels, etc., which complicates modelling. On the other hand, the way in which inverter-based resources interact with the grid is largely dependent on the characteristics of the power controller design more so than the power source (i.e., battery) itself. This means that SLB companies may be primarily tasked with detailed modelling of their power conversion system rather than battery electrochemical behaviour. Although battery energy efficiencies will impact the system round-trip efficiency figures required by the power system model, the interviewed grid operators indicated that the accuracy of this particular figure is not critical for interconnection approval. Still, power conversion systems can also be more complex for SLBs than new batteries, presenting another potential challenge for SLB companies seeking FTM interconnection. Even if the model proves to be no more complicated than a new-build BESS, the necessity of such advanced modelling may still be a barrier to entry for small SLB startup companies seeking to build FTM systems capable of providing ancillary services. One of the interviewed grid operators stated that the only alternative to building a model is contracting advanced high-resolution testing on a built product to measure real interactions with a grid interface so that a model can be fitted to the results, which is also no small task. Utility-scale applications are therefore more likely to be served by SLB companies with substantial experience and expertise.

Even for some BTM systems, interconnection requirements can be burdensome. One interviewed grid operator incentivizes BESS projects to connect to the grid operator's DERMS platform, with vendors (including SLB companies) reportedly taking many months to pass all the tests required for interconnection to the system. Long interconnection delays can potentially create economic challenges for SLB startup companies trying to launch early BTM projects. Furthermore,

interconnection requirements typically include safety certification requirements such as UL 9540, which many SLB companies are already struggling with as described in Section 3.3.1.

Though SLB companies may encounter potential difficulties with interconnection, grid operators are generally technology agnostic and do not explicitly discourage or favour repurposed products like SLBs when considering a proposed interconnection. All the interviewed grid operators agreed that as long as the interconnection requirements are met (including safety certifications) and there are no issues raised in the power system model, an SLB system can be connected to the grid. One interviewee suggested that additional requirements might be appropriate for SLBs in residential applications where monitoring and maintenance might be lacking, but this would be up to certification standards rather than grid operators.

### **4.3 Economic considerations**

Being generally technology agnostic, grid operators rely on economic models to select the most cost-effective project proposals and optimally dispatch the resources in a power system at least cost. In proposing an SLB project, an SLB company would be expected to provide information on capital costs, operating costs, lifetime guarantees, performance guarantees, degradation curves, and augmentation plans as inputs to the economic model for comparison against other proposals, including new-build BESS. To compete with new-build BESS, the lower capital cost of an SLB project would have to economically offset the effects of shortened lifetime and accelerated degradation.

Grid operators require high confidence levels in the submitted cost estimates they feed into their economic models, and this presents a potential difficulty for SLB companies. Whereas new batteries can be priced fairly accurately, SLB supply chains are still fragmented and inconsistent, leading to a wider spectrum of used EV battery prices. This would mean that a grid operator's economic model would have to produce a wider band of cost outcomes, which could potentially be a disadvantage when compared to a new-build BESS with a relatively narrow cost band.

Another economic consideration is project lifetime. One interviewed grid operator shared that their BTM BESS programs are typically offered for 10-year project lifespans, which aligns well with the 10-to-15-year warranty typically offered by SLB companies. Other grid operators explained that since utility-scale BESS projects are commonly procured for a 20-to-25-year lifespan, an SLB company would be expected to include in their proposal an augmentation plan to demonstrate how the SLB system could still meet the required project lifetime through battery replacements, the cost of which would be accounted for in the economic model. One interviewed grid operator felt that there might be an advantage in working with individual EV battery units that can be deployed in a "plug and play" system where the balance of plant is otherwise the same as a new-build BESS and EV batteries are swapped in and out relatively easily to extend the system life.

One of the interviewed grid operators described specific electricity market procurements that might be well suited to SLB projects with lifetimes of 10 to 15 years. They stated that capacity auctions tend to be on shorter timeframes and that this might align well with SLB lifetimes. They further described an annual capacity auction that is tailored for end-of-life resources such as old solar/wind farms that can be kept online for relatively short blocks of time. The interviewee suggested that SLBs could be a good use case for these annual capacity markets.

#### **4.4 Confidence building**

Despite being generally technology agnostic, some of the interviewed grid operators expressed a degree of hesitation around SLBs as a relatively new technology being deployed by relatively new SLB companies. One interviewee felt that a marginal cost saving (e.g., 10 %) per unit service, might not be sufficient to justify selecting an SLB project over a new-build BESS, due to uncertainties around the nature of SLB technology. This hesitation indicates that it may take more time for SLB technology to become more widely familiar and proven to grid operators before SLB systems are weighed against new-build BESS through a purely economic lens.

Some grid operators indicated that beyond economic modelling, they would ask additional questions about whether a new technology has been deployed elsewhere, the scale of existing projects, and the track record of the company proposing the project. One grid operator shared that while they are open to partnering on subsidized pilot projects, they generally do not want to be the first to deploy a new technology at scale. However, they also stated that with an appropriate level of performance guarantees, certifications, and documentation, confidence can be built in both the technology and the company so that innovative projects can move forward.

## 5 Conclusions and Recommendations

This stakeholder research project has compiled the perspectives of eight North American SLB companies and five Canadian electrical utilities and electricity system operators to paint a picture of the current state of the North American SLB industry and the opportunities for greater SLB participation in Canadian electricity systems, with a focus on ancillary service provision. This section summarizes the major findings of our study and offers ten recommendations.

### 5.1 A diverse and evolving industry

One of the most striking observations from this project is the degree of variety among different SLB companies in North America. Among eight such companies, most were unique in terms of battery sources, technology, design preferences, scale, and market segments. This variety demonstrates three key findings:

- 1) The industry is immature such that specific technological solutions and business models have not yet emerged as the most cost-effective options. Many companies are still using early-stage funding to explore different design options and pilot projects. The industry still has to grow significantly and become profitable before manufacturers and project developers determine the best ways to design and operate SLB systems, especially at the utility scale.
- 2) Supply chains are underdeveloped, leading most SLB companies to partner with one or two EV OEMs so they can secure a consistent, cost-competitive battery supply. This model is presently working for these relatively early-stage companies, but scalable SLB business models will require more streamlined supply chains for used EV batteries, especially as more SLB companies enter the space in the coming years.
- 3) Despite the wide range of energy storage applications being pursued, one commonality is that almost all existing projects have been behind the meter, with minimal progress into front-of-the-meter applications like ancillary services. The main reason for this seems to be the scale of new-build BESS competition (hundreds of MWh or GWh) compared with the relatively small size of most SLB companies, as well as the complexities of certification.

With many SLB companies still in early development and innovating new solutions, it will be interesting to watch the sector as new operational models and business models work their way into the commercial space. There appear to be many opportunities for research and development partnerships between industry, government, and academia.

### 5.2 Challenges and solutions

Though SLB companies largely go through the same regulatory steps as new-build BESS companies, they face three additional regulatory hurdles:

- 1) The requirement to certify their manufacturing facility under UL 1974 according to the prescribed repurposing processes.
- 2) The requirement to retroactively certify their acquired EV batteries under UL 1973 instead of purchasing pre-certified stationary batteries.
- 3) The requirement to redo expensive UL certifications each time they want to start sourcing a different EV battery type.

While some SLB companies have had success in obtaining UL certifications for their projects, there is largely a consensus in the industry that the current regulatory framework makes it difficult for SLB companies to scale up. UL 1973 is inherently unaccommodating to SLBs unless the SLB company has a close working relationship with the OEM, and most companies find UL 1974 to be cumbersome. Furthermore, companies looking to diversify their battery sources face substantial costs to certify each unique battery type. Some companies are working around these regulatory barriers by targeting jurisdictions with risk-tolerant AHJs, but these opportunities are too scarce to be scalable. The long-term solution is to revise these standards to make them more accommodating to SLBs without sacrificing product safety and reliability. Industry leaders are already working collaboratively to make those revisions happen through a concerted effort with standards organizations like UL.

According to the interviewed SLB companies, the main technical challenges of SLBs compared to new-build BESS are related to:

1. The inherent variance in the supply of used EV batteries, both in terms of battery designs and battery degradation.
2. The question of whether to install active cooling capabilities and risk additional failure points.
3. The question of whether to operate SLBs more conservatively to accommodate performance limitations compared to new-build BESS.
4. The necessity to innovate new solutions in battery monitoring and control.

Ancillary services, as FTM services, are inherently large scale, potentially requiring tens of thousands of used EV batteries. This likely means that such systems will have to accommodate multiple unique EV battery types, which may vary in capacity, voltage, SOH, chemistry, etc. This kind of system is far more challenging from a technical standpoint, and the current regulatory environment also makes it more difficult to achieve safety certification on a mixed-battery system. As some SLB companies have noted, granular power conversion architectures allow for monitoring and control at the level of individual battery packs or modules, and this appears to be a pathway to overcome the technical challenges of building utility-scale SLB systems capable of providing ancillary services. In fact, each of the technical challenges listed above can be at least partially addressed by a granular power conversion architecture. This shows how industry innovation is already overcoming technical challenges.

### **5.3 Openness from utilities and electricity system operators**

Two of the interviewed SLB companies reported interactions with utility companies in the United States that were reluctant to entertain SLB technology as a near-term solution for utility-scale energy storage. However, our conversations with Canadian utilities and electricity system operators did not reflect that sentiment. While interviewees occasionally raised a hesitation or extra question about SLBs, they largely seemed open to SLB technology as long as it could compete economically with alternatives like new-build BESS. They were even optimistic about how a shorter-lifetime product like an SLB could still compete if the project proposal was well thought-out. However, there is justifiably more hesitation around working with small startups that are new to the space, and small startups may also lack the modelling capabilities needed to meet the stringent requirements for large-scale interconnections. The challenge for smaller SLB companies will likely be to gradually establish a proven track record of successful projects, likely starting with smaller BTM projects and

gradually building up to utility-scale FTM projects, so that system operators (as well as project financiers and insurers) will support the SLB company and their proposed projects. Partnering on government-funded pilot projects is another potential avenue into the utility space.

In terms of ancillary services, it appears the question is not whether SLB projects will be eligible to provide these services, but whether a given jurisdiction will have an economically viable market for these services. Other than battery certification requirements, we heard of no extra interconnection approval steps that SLB companies would have to navigate because of the SLB technology itself. We did however hear that some ancillary service markets are growing while others are reducing, and the landscape seems to be evolving rapidly. Presently, the most economical path seems to be to building business models based not on ancillary services but on energy services that support the changing supply-demand dynamics of our electricity systems. If an SLB project can establish profitability in energy services, then a portion of its capacity can be offered for ancillary services.

#### **5.4 Recommendations to support industry growth**

SLB companies face many challenges, and some can only be overcome through technological innovation and internal business development. However, our stakeholder research revealed many opportunities for Government to support the growth of the SLB industry into ancillary service markets and beyond:

1. Encourage certification bodies to work with industry on revising standards that create barriers to SLB project approvals.
2. Create funding programs that subsidize the cost of certification for small SLB startup companies.
3. Build networks that streamline used EV battery supply chains.
4. Offer grants to support new technological innovations that advance the SLB industry (potentially in partnership with research institutions), such as unique designs that improve cost effectiveness, safety, and reliability.
5. Encourage grid operators to create educational resources for small SLB companies seeking to develop a viable pathway to utility-scale interconnection approvals.
6. Facilitate dialogue between grid operators and SLB industry representatives to reduce negative misconceptions about SLBs and raise awareness about the potential advantages that SLBs can offer over new-build BESS.
7. Explore ways to drive the electricity sector from a technology-agnostic model to one that inherently favours more circular technologies like SLBs.
8. Offer pilot project funding programs that foster partnerships between grid operators and SLB companies.
9. Identify jurisdictions with the greatest projected future demand for ancillary services and focus SLB supports in those jurisdictions.
10. Facilitate market entry for small SLB startup companies by prioritizing them when low-risk BESS project opportunities arise (e.g., remote locations) where expensive and laborious certification processes are less critical.

## **5.5 Acknowledgements**

We greatly appreciate all stakeholders who generously gave their time and shared their valuable insights and experiences with us. This project would not have been possible without their openness and eagerness to evolve the electricity sector and utilize the resource of used EV batteries.

## References

- [1] C. White, R. Ning, M. Gregory, B. Ellis, and L. G. Swan, "Second-Life Batteries for Ancillary Services: Literature Review and Technical Assessment," Dalhousie University, report submitted to National Research Council Canada (contract #1021365), Apr. 2025.
- [2] UL Standards & Engagement, *Lithium Batteries*, UL 1642, 2022.
- [3] International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications - Part 2: Lithium systems*, IEC 62133-2, 2017.
- [4] International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for portable applications - Part 3: Prismatic and cylindrical lithium secondary cells and batteries made from them*, IEC 61960-3, 2017.
- [5] National Fire Protection Association, "NFPA 800 Standards Development." [Online]. Available: <https://www.nfpa.org/codes-and-standards/nfpa-800-standard-development/800>
- [6] CSA Group, "NFPA 800: A New Standard for the Energy Storage Lifecycle." [Online]. Available: [https://www.csagroup.org/testing-certification-testing-lsft-hub-lsft-knowledge-hub/nfpa-800-a-new-standard-for-the-energy-storage-lifecycle/?srsltid=AfmBOorwCe9pex4O38gK\\_O6a\\_R2G3Eqfnyp16UBQEbWQ36AYjYOiseo](https://www.csagroup.org/testing-certification-testing-lsft-hub-lsft-knowledge-hub/nfpa-800-a-new-standard-for-the-energy-storage-lifecycle/?srsltid=AfmBOorwCe9pex4O38gK_O6a_R2G3Eqfnyp16UBQEbWQ36AYjYOiseo)
- [7] United Nations, *UN Manual of Tests and Criteria ST/SG/AC.10/11/Rev.8*, Part III, Sub-section 38.3, 2023.
- [8] International Electrotechnical Commission, *Safety of primary and secondary lithium cells and batteries during transport*, IEC 62281, 2019.
- [9] UL Standards & Engagement, *Measuring and Reporting Circularity of Li-ion and Other Secondary Batteries*, UL 3601, 2025.
- [10] Standards Council of Canada, "Battery Circularity Standard." [Online]. Available: <https://scc-ccn.ca/standards/notices-of-intent/csa-group/battery-circularity-standard>
- [11] UL Standards & Engagement, *Batteries for Use In Electric Vehicles*, UL 2580, 2022.
- [12] UL Standards & Engagement, *Batteries for Use In Light Electric Vehicle (LEV) Applications*, UL 2271, 2023.
- [13] SAE International, *Recommended Practice for Performance Rating of Electric Vehicle Battery Modules*, SAE J1798, 2019.
- [14] SAE International, *Guidelines for Electric Vehicle Safety*, SAE J2344, 2020.
- [15] SAE International, *Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells*, SAE J2929, 2013.
- [16] SAE International, *Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing*, SAE J2464, 2021.
- [17] SAE International, *Vibration Testing of Electric Vehicle Batteries*, SAE 2380, 2021.
- [18] SAE International, *Recommended Practice for Electric, Fuel Cell and Hybrid Electric Vehicle Crash Integrity Testing*, SAE J1766, 2014.

- [19] SAE International, *Recommended Practices for Shipping Transport and Handling of Automotive-Type Battery System - Lithium Ion*, SAE J2950, 2020.
- [20] United States National Highway Traffic Safety Administration, *Electric-Powered Vehicles: Electrolyte Spillage and Electrical Shock Protection*, FMVSS 305, 2017.
- [21] International Electrotechnical Commission, *Degrees of protection provided by enclosures (IP Code)*, IEC 60529, 2013.
- [22] International Electrotechnical Commission, *Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 1: Performance testing*, IEC 62660-1, 2018.
- [23] International Electrotechnical Commission, *Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 2: Reliability and abuse testing*, IEC 62660-2, 2018.
- [24] International Electrotechnical Commission, *Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 3: Safety requirements*, IEC 62660-3, 2022.
- [25] International Electrotechnical Commission, *Secondary lithium-ion cells for the propulsion of electric road vehicles - Part 4: Candidate alternative test methods for the internal short circuit test of IEC 62660-3*, IEC 62660-4, 2017.
- [26] International Organization for Standardization, *Electrically propelled road vehicles — Test specification for lithium-ion traction battery packs and systems Part 4: Performance testing*, ISO 12405-4, 2018.
- [27] International Organization for Standardization, *Electrically propelled road vehicles — Safety specifications Part 1: Rechargeable energy storage system (RESS)*, ISO 6469-1, 2019.
- [28] United Nations, *Uniform provisions concerning the approval of vehicles with regard to specific requirements for the electric power train*, ECE R100, 2024.
- [29] United Nations, *Uniform provisions concerning the approval of vehicles of category L with regard to specific requirements for the electric power train*, ECE R136, 2016.
- [30] UL Standards & Engagement, *Batteries for Use in Stationary and Motive Auxiliary Power Applications*, UL 1973, 2022.
- [31] International Electrotechnical Commission, *Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 1: Photovoltaic off-grid application*, IEC 61427-1, 2013.
- [32] International Electrotechnical Commission, *Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications*, IEC 61427-2, 2015.
- [33] International Electrotechnical Commission, *Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial application*, IEC 62619, 2022.
- [34] CSA Group, *Battery management systems*, CSA C22.2 NO. 340, 2023.
- [35] UL Standards & Engagement, *Evaluation for Repurposing or Remanufacturing Batteries*, UL 1974, 2023.
- [36] International Electrotechnical Commission, *Repurposing of secondary batteries - Part 1: General requirements*, IEC 63330-1, 2024.

- [37] International Electrotechnical Commission, *General guidance on reuse and repurposing of secondary cells and batteries*, IEC 63338, 2024.
- [38] SAE International, *Electric Vehicle (EV) Battery Traceability Record*, SAE J3327, 2025.
- [39] UL Standards & Engagement, *Energy Storage Systems and Equipment*, UL 9540, 2025.
- [40] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 1: Vocabulary*, IEC 62933-1, 2024.
- [41] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 2-1: Unit parameters and testing methods - General specification*, IEC 62933-2-1, 2017.
- [42] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 2-2: Unit parameters and testing methods - Application and performance testing*, IEC TS 62933-2-2, 2022.
- [43] International Electrotechnical Commission, *Electric energy storage (EES) Systems - Part 2-3: Unit parameters and testing methods - Performance assessment test during site operation*, IEC TS 62933-2-3, 2025.
- [44] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 2-200: Unit parameters and testing methods - Case study of electrical energy storage (EES) systems located in EV charging station with PV*, IEC TR 62933-2-200, 2021.
- [45] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 3-1: Planning and performance assessment of electrical energy storage systems - General specification*, IEC 62933-3-1, 2025.
- [46] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 3-2: Planning and performance assessment of electrical energy storage systems - Additional requirements for power intensive and renewable energy sources integration related applications*, IEC TS 62933-3-2, 2023.
- [47] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 3-3: Planning and performance assessment of electrical energy storage systems - Additional requirements for energy intensive and backup power applications*, IEC TS 62933-3-3, 2022.
- [48] International Electrotechnical Commission, *Electrical energy storage (EES) systems – Part 3-200: Planning and performance assessment of electrical energy storage systems – Design principles of electrochemical based EES systems*, IEC TR 62933-3-200, 2025.
- [49] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 4-1: Guidance on environmental issues - General specification*, IEC TS 62933-4-1, 2017.
- [50] International Electrotechnical Commission, *Electric energy storage (EES) systems – Part 4-2: Guidance on environmental issues – Assessment of the environmental impact of battery failure in an electrochemical based storage system*, IEC 62933-4-2, 2025.
- [51] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 4-3: Protection requirements of battery-based energy storage systems (BESS) according to environmental conditions*, IEC 62933-4-3, 2025.
- [52] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 4-4: Environmental requirements for battery-based energy storage systems (BESS) with reused batteries*, IEC 62933-4-4, 2023.

- [53] International Electrotechnical Commission, *Electrical energy storage (EES) Systems - Part 4-200: Guidance on environmental issues - Greenhouse gas (GHG) emissions assessment by electrical energy storage (EES) systems*, IEC TR 62933-4-200, 2024.
- [54] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 5-1: Safety considerations for grid-integrated EES systems - General specification*, IEC 62933-5-1, 2024.
- [55] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 5-2: Safety requirements for grid-integrated EES systems - Electrochemical-based systems*, IEC 62933-5-2, 2025.
- [56] International Electrotechnical Commission, *Electrical energy storage (EES) systems - Part 5-3: Safety requirements for grid-integrated EES systems – Performing unplanned modification of electrochemical based system*, IEC 62933-5-3, 2023.
- [57] UL Standards & Engagement, *Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources*, UL 1741, 2025.
- [58] CSA Group, *Power conversion equipment*, CSA C22.2 No. 107.1, 2021.
- [59] Institute of Electrical and Electronics Engineers, *Storage Batteries*, IEEE C2: National Electrical Safety Code, Section 14, 2023.
- [60] CSA Group, *Renewable Energy Systems*, CSA C22.1: Canadian Electrical Code, Part I, Section 64, 2024.
- [61] National Fire Protection Association, *Energy Storage Systems*, NFPA 70: National Electrical Code, Article 706, 2023.
- [62] National Fire Protection Association, *Standard for the Installation of Stationary Energy Storage Systems*, NFPA 855, 2026.
- [63] International Code Council, *Electrical Energy Storage Systems (ESS)*, International Fire Code, Section 1207, 2024.
- [64] UL Standards & Engagement, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*, UL 9540A, 2026.
- [65] National Fire Protection Association, *Standard on Explosion Prevention Systems*, NFPA 69, 2024.
- [66] National Fire Protection Association, *Standard on Explosion Protection by Deflagration Venting*, NFPA 68, 2023.
- [67] Institute of Electrical and Electronics Engineers, *Interconnection and Interoperability of Inverter-Based Resources (IBRs) Interconnecting with Associated Transmission Electric Power Systems*, IEEE 2800, 2022.
- [68] Institute of Electrical and Electronics Engineers, *Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces*, IEEE 1547, 2018.
- [69] Y. Preger, L. Torres-Castro, T. Rauhala, and J. Jeevarajan, "Perspective—On the Safety of Aged Lithium-Ion Batteries," *J. Electrochem. Soc.*, vol. 169, no. 3, p. 030507, Mar. 2022, doi: 10.1149/1945-7111/ac53cc.

- [70] G. G. Gerosa *et al.*, "Impact of Testing Method on Safety Assessment of Aged Li-ion Cells: Part I – Li Plating as Main Aging Mechanism," *J. Electrochem. Soc.*, vol. 172, no. 3, p. 030502, Mar. 2025, doi: 10.1149/1945-7111/adb804.
- [71] Y. Preger *et al.*, "Impact of Testing Method on Safety Assessment of Aged Li-Ion Cells: Part II – Aged Cells Without Li Plating," *J. Electrochem. Soc.*, vol. 172, no. 8, p. 080503, Jul. 2025, doi: 10.1149/1945-7111/adeed0.
- [72] IESO, "2026 Annual Planning Outlook," Mar. 2026.