What Data Do Autonomous Underwater Vehicle Battery-State Estimation Methods Need, and What Does Open Data Leave Unmet? A Survey (2020–2026)

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Abstract — Estimating the state and endurance of autonomous underwater vehicle (AUV) batteries needs electrical, thermal, ageing and vehicle-context data, and the open data identified covers only part of that need. This survey examines 20 studies from 2020 to 2026 on state of charge, state of health, capacity and energy estimation for AUVs and unmanned underwater vehicles. Temperature is varied in 9 of the 20, hydrostatic pressure in 2, and real vehicle trial data are used in 4. No record read combines pressure, temperature, ageing and mission data in one study. The principal open datasets are terrestrial cell tests from NASA, CALCE and Oxford. One open AUV battery log exists (MBARI, 2003), but it has no state-of-charge reference, ageing history, pressure or mission context. Open data therefore exists but is insufficient for the data combinations these methods need. All 20 studies were read in full text, so a missing item is read as "not stated" and never as "not done".

Keywords — Autonomous underwater vehicle; Battery state estimation; State of charge; Open data; Evidence gap; Naval systems

NOMENCLATURE

AUV, Autonomous underwater vehicle; UUV, Unmanned underwater vehicle; SOC, State of charge; SOH, State of health; RUL, Remaining useful life; OCV, Open-circuit voltage; EKF, Extended Kalman filter; HPPC, Hybrid pulse power characterisation; DST, Dynamic stress test; FUDS, Federal urban driving schedule; HWFET, Highway fuel economy test; C, C-rate (current as a multiple of rated capacity, h^{-1}); MPa, Megapascal (hydrostatic pressure).

I. INTRODUCTION

Autonomous underwater vehicles (AUVs) are used for survey, inspection and naval tasks, and the battery sets how long and how far they can work [19], [20]. A vehicle whose remaining usable energy at depth is uncertain must be planned conservatively or risk loss, which makes battery-state knowledge a mission-planning input for defence and naval operations as much as a laboratory topic. Energy and power systems for underwater vehicles have been reviewed over many years [20], [21]; this survey asks the narrower data question below.

AUV battery estimators borrow their methods from electric vehicles, but their operating conditions differ in at least four ways. Missions are long and mostly low-current: Lim et al. describe UUV operation of up to 40 days with almost no rest, at average rates of 0.02C to 0.1C [12]. Deep-sea cells sit under hydrostatic pressure, which two studies report affects electrochemical performance and SOC modelling [4], [8]. Water temperature varies widely, and several estimators are built specifically for low-temperature operation [5], [7]. Some vehicles carry primary lithium cells, which do not cycle but lose capacity in storage [3], [9].

What an estimator can claim depends on the data it was built and tested on. A method calibrated on a room-temperature cell test says little about a cell at depth, and a method tested only on a car driving schedule says little about a hovering vehicle. The question for this survey is therefore about data, not algorithms:

What data do published methods for estimating AUV battery state and endurance need, and which of those needs does open data leave unmet?

The survey makes three contributions. It tabulates, for 20 studies, the data each used or reported (Section III). It lists the open datasets that could be identified and examines what each offers (Section III-B). It separates the existence of open data from its sufficiency for AUV use (Section IV). It does not rank estimation algorithms: the reported errors come from different cells, protocols and reference definitions and are not comparable.

II. METHODS

This is a structured evidence-gap survey, not a systematic review. The first search was carried out in November 2026 using a web search engine, publisher and repository pages, and the NASA data portal. A Scopus search followed on 16 November 2026. It covered titles, abstracts and keywords from 2020 onwards and combined underwater-vehicle terms, battery terms and state terms (state of charge, state of health, remaining useful life, energy estimation, endurance and capacity). The query was: TITLE-ABS-KEY (("autonomous underwater vehicle*" OR auv OR "unmanned underwater vehicle*" OR uuv OR "underwater glider*" OR "underwater vehicle*") AND (battery OR batteries OR "lithium") AND ("state of charge" OR "state of health" OR soc OR soh OR "remaining useful life" OR "energy estimation" OR endurance OR capacity)) AND PUBYEAR > 2019. It returned 191 records. Thirteen of the 15 studies already included were among them; the other two are a thesis [14] and one article [15]. Screening of titles and abstracts added five studies [25]–[29]. A ScienceDirect search on 17 November 2026 (title, abstract and keywords, 2020 onwards) returned 69 records; six were already included and one pack-design study was added as context [31]. Most of the other records concern wireless charging, fuel cells, thermal management, docking or vehicle design. Web of Science was not searched, so the list of studies may still be incomplete.

Inclusion. A study was included if it was published between 2020 and 2026 as a peer-reviewed article, a proceedings paper or a thesis, and estimated SOC, SOH, capacity, remaining useful life (RUL), ageing or energy use for the battery of an AUV, UUV or other underwater vehicle. Eight studies [6], [7], [13], [15], [22], [27], [28], [29] use underwater vehicles only as motivation and run their tests on terrestrial or laboratory data. They were kept and flagged, because they show what data underwater-framed methods are actually built on.

Not counted. Six further records were identified and left out: one published before 2020, one whose abstract and DOI could not be retrieved, one conference paper that overlaps study 12, one electric-vehicle paper of borderline scope, one conference paper whose full text could not be obtained, and one article, reference [11] (Li et al., 2024), which its publisher withdrew from online distribution on 17 October 2024 because some of its data were not rigorous or accurate. A 2025 review of deep-sea battery manufacturing was used as context only [19].

Extraction. For each study the platform and target quantity were recorded, followed by the data attributes below. Voltage and current are the baseline measurements of the cell-level methods and are not tabulated separately.

- chemistry and cell type; cell or pack level
- hydrostatic pressure or depth; temperature range
- load or current profile; charge–discharge history
- cycle or ageing data; mission or operational data, including environmental variables
- ground truth or end point used as the reference
- statement on public data availability; validation level

Evidence basis. All 20 studies were read in full text [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [12], [13], [14], [15], [22], [25], [26], [27], [28], [29]. The record of one study is a single page [6]. The five found through the Scopus search [25]–[29] include one article that replaced a conference paper whose full text could not be obtained. In Table I, "n/s" means not stated in the record read; it does not mean the study omitted the item. All 20 included studies were checked against a publisher, repository or aggregator record, and the DOI or handle of each was confirmed.

Framing rule. The survey distinguishes whether open data exists from whether it is sufficient for the data combinations that AUV studies use. It does not claim that open AUV battery data is absent.

III. RESULTS

A. Data used by the 20 studies

The 20 studies mostly use laboratory cell tests with electrical and temperature data, and few add pressure, ageing or vehicle mission data. By target quantity, eight estimate SOC alone, one SOC and SOH jointly, three SOH, five capacity or capacity loss, two energy use, and one RUL. Table I gives the extraction. Each row rests on a full-text reading of the study.

Table I. Data used or reported by each study. "n/s" = not stated in the record read; "none" = the record describes no such variable. Study numbers are reference numbers; reference 11 is excluded (see Section II).

Study	Target	Cell / chemistry	Pressure	Temp.	Ageing data	Mission data	Own data open?	Basis
S1 [1]	SOC	Li-MnO2 primary, 11.5 Ah	none (lake depths 12, 24 m)	0–30 °C	none	lake trial	none stated	full text
S2 [2]	Glider energy use	not stated	depth as model input	n/s	n/s	sea-trial data	n/s	full text

Study	Target	Cell / chemistry	Pressure	Temp.	Ageing data	Mission data	Own data open?	Basis
S3 [3]	Capacity	primary lithium, 22 Ah	none	varied	calendar, 90 days	none (lab only)	n/s	full text
S4 [4]	Performance, capacity loss	NCM811 soft-pack, 5 Ah	0.1–90 MPa	room temp. only	600 cycles	none	authors cannot share	full text
S5 [5]	SOC	LiFePO4 6 Ah cell	none	−20, 0, 30 °C	none (future work)	none	no statement	full text
S6 [6]	SOH	LiFePO4, 2 Ah as stated; NASA data	named, not varied	4, 24, 43 °C	fade 100% to 70%	none stated	NASA cell data, set not named	full text
S7 [7]	SOC	Panasonic 18650PF, 2.9 Ah (public)	none	five settings, −20 to 25 °C	none (new cell)	none (drive cycles)	public [30]; own on request	full text
S8 [8]	SOC	NCM soft-pack, 4.4 Ah	0.1, 30, 60 MPa	n/s	none (new cell)	none (HPPC test)	authors cannot share	full text
S9 [9]	Early capacity	Li/SOCl2 primary, 22 Ah	none	storage 0–54 °C; discharge varied	calendar, 6 months	test matrix from AUV working modes (lab)	on request	full text
S10 [10]	SOC and SOH	NMC 10 Ah cell	none	not varied	cycles 0–1000	none	uses NASA data for a check	full text
S12 [12]	SOC	72 Ah pouch cell	none	25 °C only	none	simulated, HWFET-based	on request	full text
S13 [13]	RUL	Li-ion, 8 public cells	none	not varied	fade (NASA, CALCE)	none	terrestrial public data	full text
S14 [14]	Mission energy	pack, 208 INR18650 cells	none	not modelled	not modelled	tank and field trials	n/s	full text
S15 [15]	Capacity, energy, SOC	LiFePO4 105 Ah cell	not reported	nine settings, −20 to 55 °C	none (one cycle per setting)	none	“Not applicable”	full text
S22 [22]	SOC	Panasonic 18650PF, 2.9 Ah (public data)	none	five settings, −20 to 25 °C	none (new cell)	none (road driving cycles)	Panasonic 18650PF and CALCE public data	full text
S25 [25]	Effective capacity	Li/SOCl2, 19 Ah (ER34615)	none (depth sets sea temp.)	−30 to 85 °C, six levels	none (fresh cells)	sea trial, May 2023	on request; capacity data in Dataset S1	full text
S26 [26]	SOC (path planning)	LiFePO4 pack, 32 cells, 3 kWh	none	omitted by model	none	none (simulated task)	in article; authors on request	full text
S27 [27]	SOH	LiCoO2: CALCE CS2 pouch, own 18650 2.4 Ah	none	room temp. only	cycling; SOH to 0.2 (CALCE), 0.8 (own)	none (constant 0.5, 1, 2.5 C rates)	CALCE public; own on request	full text
S28 [28]	SOH	LiCoO2: CALCE CS2 pouch, own 18650 2.4 Ah	none	25 °C only	cycling; SOH to 0.2 (CALCE), 0.8 (own)	none (constant 0.5, 1, 2.5 C rates)	CALCE public; own data via authors	full text
S29 [29]	SOC	LiFePO4 105 Ah cell	none	thermal chamber, setpoint n/s	none stated	none (DST, road-vehicle profile)	none stated	full text

Level and protocol. Where the level is stated, twelve studies test single cells and one tests a pack [14]. Three use test protocols derived from road vehicles: HPPC and DST [5], OCV, HPPC, DST and FUDS [10], and the HWFET cycle [12]. A fourth validates on road driving cycles, including UDDS, US06, LA92 and HWFET [22]. A fifth uses the DST profile [29]. Lim et al. state that real UUV operating data were not usable because of security and accessibility constraints [12].

Temperature. Nine studies vary temperature [1], [3], [5], [6], [7], [9], [15], [22], [25]. The widest range is −30 to 85 °C in six settings [25], then −20 to 55 °C in nine settings [15]. One uses five settings from −20 to 25 °C [22]. One study tests only at 25 °C [12]. One more tests only at 25 °C [28], one tests its own cells at room temperature [27], and one laboratory study in a thermal chamber does not state its setpoint [29]. One thesis states that its battery model ignores temperature [14].

Pressure. Only two studies vary hydrostatic pressure: 0.1 to 90 MPa [4], and 0.1, 30 and 60 MPa [8]. Both use soft-pack NCM cells in the laboratory (5 Ah and 4.4 Ah), and they come from the same research group: study 8 builds on study 4.

Study 4 tests at room temperature only and study 8 does not state its temperature, so neither pressure study shows pressure and temperature together. Neither study shares its data. A pack-design study, not an estimation study, also tested a pack at 60 MPa and found a higher terminal voltage, and its authors cannot share the data [31]. One glider study uses diving depth as a model input for energy use, not as a battery test condition [2].

Ageing. Eight studies involve ageing, cycling or fade data [3], [4], [6], [9], [10], [13], [27], [28]. Two of these cover calendar ageing of primary cells [3], [9]. Only three follow cells through whole-life cycling and validate at several ages: one on its own cells [10], and two on public CALCE cells with their own cells cycled to 80% SOH [27], [28]. Six SOC studies report no ageing data [1], [5], [7], [8], [12], [29].

Mission and environment. Three studies use data from vehicle trials: a lake trial [1], sea-trial data [2], and tank and field trials [14]. A fourth checks a battery thermal model against sea-trial measurements [25]. One builds its test matrix from AUV working modes [9] and one simulates the profile [12]. Two set three constant discharge rates to stand for AUV cruising and manoeuvring modes [27], [28]. Only study 14 reports an environmental influence on energy use, namely water current. Study 2 uses diving depth as a model input, as noted above.

Reference values. Where stated, the reference is reference SOC from current integration of cycler data [5], [12], an OCV–SOC relation [15], or measured capacity [9], [10], [27]. None of the records read describes an independent on-vehicle reference.

Data availability. None of the records read states that the study's own data are deposited in an open repository. One offers data on request [12] and one states "Not applicable" [15]. Two refer data requests to their authors [26], [28]. Four more offer data on request [7], [9], [25], [27], and two state that the authors do not have permission to share data [4], [8]. One of the four also supplies the cell capacity data behind its capacity map as a supplementary dataset [25]. Seven studies use public data: a NASA cell tested at 4, 24 and 43 °C [6], NASA 18650 data to check SOH factors [10], the Panasonic 18650PF and CALCE cell data [22], CALCE CS2 cells beside its own cell tests [27], [28], the Panasonic 18650PF data [7], and NASA and CALCE data alone [13].

Combinations. No record describes pressure, temperature, ageing and mission data together in one study. The nearest are study 9, which has temperature, storage ageing and working-mode tests but no pressure, and study 4, which has pressure and cycling but tests at room temperature only.

B. Open data landscape

The principal open datasets identified are terrestrial cell tests, plus one real AUV battery log that is small and thin. Table II describes each. The NASA, Oxford and MBARI records were examined directly. The Panasonic set is described from studies 7 and 22, and its record was not examined. The NASA Randomized Battery Usage sets are released as US Government works. The catalogue record of the NASA Battery Data Set gives no licence, and the Oxford dataset is released under the Open Database License. CALCE asks that publications cite the articles describing its experiments. No terms of use were found for the MBARI file. None of the datasets was reused or redistributed here.

Table II. Open datasets identified (November 2026).

Dataset	Content	Access	Relevance to AUV use
NASA Randomized Battery Usage sets [16]	18650 Li-ion cells under random-walk charge and discharge currents, with reference cycles interleaved. Sets at room temperature, about 40 °C and low temperature	Public; released as US Government works	Terrestrial cells. No pressure, no vehicle mission
NASA Battery Data Set [23]	18650 Li-ion cells, nominal 2 Ah, cycled through charge, discharge and impedance measurements at different temperatures until 30% capacity fade (2 to 1.4 Ah)	Public; the catalogue record gives no licence	Terrestrial cells with ageing at stated temperatures. No pressure, no vehicle mission. Studies 6, 10 and 13 use NASA cell data, but the records read do not always name the set
Oxford Battery Degradation Dataset 1 [24]	Eight Kokam 740 mAh pouch cells aged in a thermal chamber at 40 °C under urban-drive-cycle profiles, with characterisation tests every 100 cycles	Public; Open Database License	Terrestrial pouch cells, one temperature. Ageing data, no pressure, no vehicle mission
Panasonic 18650PF Li-ion battery data [30]	One new 2.9 Ah Panasonic 18650PF cell tested in a thermal chamber over nine drive cycles at five temperatures, as described in study 22	Public (Mendeley Data); terms not examined	Terrestrial cell under road driving cycles, −20 to 25 °C. No ageing, no pressure, no vehicle mission. Used in study 22

Dataset	Content	Access	Relevance to AUV use
CALCE battery data [17]	Cylindrical, pouch and prismatic cells. Study 28 describes its CS2 cells as 1.1 Ah LiCoO2 pouch cells cycled to about 0.2 SOH; the CALCE pages were not examined here	Public; asks users to cite the CALCE articles describing the tests	Terrestrial cells
MBARI Bluefin battery log, deployment 2003.206.02 [18]	Three batteries, eight variables each: time, nominal voltage, nominal current, internal temperature, minimum and maximum cell-brick voltage, water-leak code, remaining capacity (Wh). 247 samples	Public through OPeNDAP; no terms of use found	Real AUV battery telemetry. One deployment, no SOC variable, no controlled ageing history, no pressure or mission context

The MBARI file matters because it shows that open real-vehicle AUV battery telemetry exists. It is a counter-example to any claim that open AUV battery data is absent. It is also a weak substitute for the experimental data in Table I, for the reasons in its last cell.

Table III sets the data needs seen in Section III-A against what the identified open data covers.

Table III. Data needs of the 20 studies against identified open data.

Data need	Studies using it (of 20)	Identified open data
Voltage and current with a reference state	baseline for cell-level methods	NASA and CALCE (terrestrial). MBARI has voltage, current and remaining capacity but no SOC variable
Temperature range	9	NASA Battery Data Set at several temperatures; Panasonic 18650PF data at five temperatures; Oxford at 40 °C only. MBARI logs internal temperature for one deployment. CALCE not examined in detail
Hydrostatic pressure	2	None identified
Ageing, cycling or capacity fade	8	NASA, CALCE and Oxford capacity-fade data; NASA and CALCE data are used in study 13. None identified for underwater-vehicle cells
Vehicle mission or trial data	4 from trials, 1 simulated	MBARI, one 2003 deployment
Environmental variables, such as water current	1	None identified
Several of the above in one dataset	0	None identified

IV. DISCUSSION

Open data exists for AUV battery estimation, but what was identified covers the electrical and temperature needs far better than the pressure, ageing and mission needs. Three observations support this.

First, AUV studies lean on in-house or institutional data. Most Table I rows rest on laboratory tests the authors ran themselves, and none of the records read states an open deposit of those data. The authors of one study say real UUV data were restricted by security and accessibility constraints and substituted a road-vehicle cycle [12]. That is a stated reason for the gap, not a failing of that study.

Second, where AUV-framed methods meet open data, the data are terrestrial. One study takes its ageing data from a NASA cell tested at three temperatures [6], one checks SOH factors on NASA 18650 data [10], one uses the Panasonic 18650PF and CALCE cell data [22], one pairs CALCE CS2 cells with its own 25 °C tests [28], another with its own room-temperature tests [27], one evaluates on the Panasonic 18650PF data [7], and one tests only on NASA and CALCE data, with underwater use as motivation [13]. These are reasonable choices given what is open. They also mean the published accuracy of those methods says little about pressure, depth or mission effects.

Third, the one real-vehicle log found cannot stand in for the experimental data. It covers a single 2003 deployment with 247 samples, and it has no SOC variable, ageing history, pressure or mission context [18]. Existence is therefore not in doubt. Sufficiency is: no single identified dataset offers the combination of pressure, temperature, ageing and mission data that the studies in Table I each draw on in part.

What would help is modest and does not depend on releasing sensitive mission data. Studies could state, in one data-availability line, which of the attributes in Section II their data contain and under what terms they can be shared. A shared cell-level dataset with pressure and temperature varied together, and one with whole-life ageing under AUV-like load profiles, would each close a gap visible in Table III.

Limitations.

- The Scopus search used one query (given in Section II) on titles, abstracts and keywords. Web of Science was not searched, so studies may still be missing.
- Only studies with an obtainable full text were included, so the list may lean toward openly or widely accessible venues. “Not stated” in Table I means the paper does not say so; it is not evidence that a study omitted the item.
- Seven of the 20 studies [3], [4], [7], [8], [9], [15], [29] share a co-author (C. Lu, Northwestern Polytechnical

University), and two more [27], [28] share two authors (B. Wang and F. Zhao, Xi'an Jiaotong University), judging by the author lists. The base is therefore clustered around a few groups and may not represent all work.

- One included study is in Chinese [10]; it was read in full.
- The open-data search covered the portals named in Section II. Datasets held elsewhere, or under access terms not seen, may exist.
- Reported errors are not compared, because cells, protocols and reference definitions differ.

V. CONCLUSION

Published AUV battery-estimation methods draw on electrical, thermal, ageing, operational and vehicle-context data, yet each of the 20 studies covers only part of that set. Temperature is common (9 of 20). Pressure (2), real trial data (4) and whole-life ageing (3) are rare. The open data identified is largely terrestrial, and AUV studies rely on experimental or institutional data. An open real-vehicle battery log exists, so the evidence supports "exists but is insufficient", not "absent".

For authors, the practical step is to state which data attributes their data contain and on what terms they can be shared. For readers, accuracy figures from room-temperature or road-cycle tests are evidence about those conditions only. The main limits are that only studies with an obtainable full text were included and that only one bibliographic database was searched.

VI. DECLARATIONS

A. Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

B. Conflict of Interest

The author declares no conflict of interest.

C. Data Availability

The datasets examined are public: the NASA Randomized Battery Usage sets [16], the NASA Battery Data Set [23], the CALCE battery data [17], the Oxford Battery Degradation Dataset 1 [24] and the MBARI Bluefin battery log [18]. None was reused or redistributed here. Table I gives the extraction behind the counts in this paper.

D. Ethics Statement

This study did not involve human or animal subjects.

E. Author Contributions

Conceptualization, Methodology, Investigation, Writing — original draft, and Writing — review and editing, G.P.V. The author has read and agreed to the published version of the manuscript.

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