GREENHOUSE GAS EMISSIONS ACCOUNTING FOR BATTERY ENERGY STORAGE SYSTEMS (BESS)

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TABLE OF CONTENTS

INTRODUCTION

The topic of greenhouse gas (GHG) emissions accounting for battery energy storage systems (BESS) is relatively new and so has not yet been thoroughly addressed by existing organization-level GHG emissions reporting guidance. This EPRI Technical Brief provides an overview of beneficial applications for integrating BESS into the electric power grid, the life-cycle GHG emissions of BESS, and how these emissions may be accounted for in electric company GHG emissions inventories.

This EPRI technical brief was prepared by the Greenhouse Gas Management Institute (GHGMI)[1]. It reflects GHGMI's best professional judgment, drawing from existing EPRI technical studies related to BESS's life cycle assessment (LCA) and other available research (see Sources).

WHAT IS GHG EMISSIONS ACCOUNTING?

Like other corporate entities, an electric company[2] may choose to report its GHG emissions by preparing a formal corporate GHG emissions *inventory*, which is an accounting of the GHG emissions and removals attributed to the company's operations and assets over a year. Several standards and guidelines[3] exist that guide corporate GHG accounting, and it is up to each company to determine how to apply these guidelines given their situation and goals.

GHG accounting *frameworks* are characterized principally by how they define system boundaries within which GHG emissions (and removals) are counted. Further, GHG accounting frameworks can either be *attributional*, meaning they focus on attributing total GHG emissions—*direct* and/or *indirect* (described below)—to entities or activities, or they can be *consequential*,[4] meaning they focus on determining net changes in GHG emissions caused by a particular intervention or decision, such as those associated with GHG "offset" projects.

Many corporate shareholders, other investors, end-users, and others concerned with corporate GHG emissions disclosure would like electric companies to develop corporate GHG emissions inventories that use more complete organizational boundaries, including indirect upstream and downstream emissions. A corporate GHG inventory is a type of attributional accounting that addresses emissions from the three GHG emissions "scopes" described below.

Some GHG reporting programs specific to the electric power sector require only *facility-based* GHG accounting and reporting, which also is an attributional method that sets the accounting boundary around individual sites or facilities. These methods do not represent the entire extent of GHG emissions that may be attributed to a power company.

1 Principal authors: T. Colbert-Sangee and M. Gillenwater. For more information about GHGMI, see https://ghginstitute.org/.

2 The term "electric company" here refers to a range of companies engaged in electric power generation, transmission and distribution activities, including vertically integrated, investor-owned electric utilities, generation and transmission cooperatives, public power agencies, transmission and/or distribution companies/entities and independent power producers.

3 Standards and guidelines include WRI/WBSCD Revised Corporate Standard (2004), TCR Electric Power Sector Protocol (2009), and others.

4 Also referred to as "causational".

TYPES OF GREENHOUSE GASES

Typically, GHG inventories include emissions of the specific GHGs listed below to the extent they are associated with emitting activities. There are additional types[5] of GHGs that may be included, but these are not required to be reported under existing GHG accounting guidance.

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Sulfur hexafluoride (SF_6)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Nitrogen trifluoride (NF_3)

To make it possible to compare the differential global warming impacts of each of these GHGs, the UN Intergovernmental Panel on Climate Change (IPCC) assesses the *Global Warming Potentials* (GWPs) of each GHG taking into account their different atmospheric lifespan and warming effect.[6]

By definition, CO_2 has a GWP equal to 1. By comparison, CH4 has a GWP of 28, and N_2O has a GWP of 265. These GWPs can be used to convert emissions of each of these GHGs into universal units called "*carbon dioxide equivalents*," referred to as "CO_2e."[7] For example, 1 metric ton ("tonne") of N_2O emissions has an equivalent warming effect of 265 tonnes of CO_2e.

Direct vs Indirect Emissions

Corporate activities may cause *direct* GHG emissions (e.g., onsite combustion of fossil fuels to generate electricity) or *indirect* emissions (e.g., purchasing goods that were manufactured by others using processes involving the combustion of fossil fuels).

Direct emissions result from sources that physically release GHGs to, or remove them from, the atmosphere and that are included within a company's operations or assets.

Indirect emissions may occur "upstream" (i.e., associated with the production of inputs used by a company), coincident with a company's activities (e.g., employee air travel emissions), or "downstream" (i.e., associated with the use or disposal of products created by a company).

GHG Emission Scopes

Emissions "scopes" are used to classify direct and different types of indirect GHG emission sources and removals by sinks.[8] The three main scopes include:

- Scope 1: Emissions physically arising from sources or sinks directly owned or controlled by an organization.
- Scope 2: Indirect emissions associated with electricity, heat, steam, or cooling purchased for use by an organization.
- Scope 3: All non-scope 2 indirect emissions attributable to an organization's activities.

A complete organizational-level GHG inventory typically includes all scope 1 emissions from activities inside the organizational boundary. Scope 2 emission sources may be included in reporting. Scope 3 emissions typically are considered "optional" for corporate reporting.

One should recognize two different organizations can report the same GHG emissions from the same source in their inventory, but ideally, these emissions would be reported under a different scope for each organization provided all the entities engaged in the "supply chain" have set their operational and organizational boundaries similarly.

For instance, retail end-use customers would classify the GHG emissions associated with electricity they purchase and consume from their electric utility as being scope 2 emissions. However, the electric company generating the electricity consumed by these customers would classify the associated GHG emissions as scope 1 direct emissions. In this way, scope categorization helps to prevent double counting of emissions between organizations within scope 1 and 2. However, this is not the case for scope 3 GHG emissions. By reporting the same source of emissions under separate scopes, an electricity provider and end-use consumer can avoid making confusing and/or contradictory claims about responsibility for emissions from a GHG emissions source. Appendix A provides examples of typical GHG emission sources for electric power sector companies organized by scopes.

5 These additional GHGs include: Trifluoromethyl Sulphur Pentafluoride (SF_5, CF_3); Halogenated Ethers (e.g., $C_4F_9OC_2H_5$, $CHF_2OCF_2OC_2F_4OCHF_2$, $CHF_2OCF_2OCHF_2$), and other halocarbons not covered by the Montreal Protocol including CF_3I, CH_2Br_2 $CHCl_3$, CH_3Cl, CH_2Cl_2.

6 GHG reporting programs often lag behind the most recent IPCC assessment report to allow time for scientific consensus to emerge around the updated GWPs. This practice reduces issues with time-series comparability and the burden to revise previously reported data until a new consensus is achieved.

7 The GWPs presented here come from the IPCC Assessment Report 5 (AR5) published in 2014. GWP values change over time as they are subject to frequent scientific study along with the preparation of IPCC Assessment Reports. Given this, it is important for companies reporting GHG emissions to follow program-specific GHG reporting guidance when selecting appropriate GWPs. For more information visit: http://www.offsetguide.org/understanding-carbon-offsets/what-is-a-carbon-offset/gwp/

8 Emission sinks sequester or absorb CO_2 from the atmosphere lowering atmospheric GHG emission levels (e.g., a forest, a wetland, a carbon capture and storage plant).

UTILITY-SCALE ENERGY STORAGE AND BESS

Electric companies in the United States started to deploy energy storage beginning in the 1950s by deploying pumped hydropower storage facilities. In these facilities, water is pumped to higher elevation storage basins and stored until it is needed. Then it is used to generated hydroelectric power at another time when it is needed to meet demand. Over the following 40 years, pumped hydro storage reached its present level of deployment at ~20 gigawatts (GW) of installed capacity and represented the dominant technology for utility-scale energy storage. Utility-scale energy storage is now rapidly evolving and includes new technologies, new energy storage applications, and projections for exponential growth in storage deployment.

The energy storage technology being deployed most widely today is Lithium-Ion (Li-Ion) battery technology. As shown in Figure 1, Li-Ion storage is expected to grow rapidly in the coming decades and may far exceed the level of pumped-hydro capacity within a few years.

Energy storage systems can be deployed in various configurations. Two important attributes of an energy storage system typically are used together to define its "size": (i) the amount of *capacity* (measured in MW) the storage system can instantaneously charge or discharge, and, (ii) the total amount of *energy* (measured in MWh) the system can deliver.

To better understand these two metrics, it may be helpful to imagine a BESS as being similar to a room with a door.[9] The size of the "door" represents the capacity of the storage system to charge or discharge, while the "size" of the room represents the total amount of energy stored by the BESS when it is fully charged. For example, a BESS with a door that allows for 1 MW of power to be charged or discharged has a 1 MW capacity. If the BESS can operate for a period of 4 hours at that 1 MW power rate, then the BESS has a room that can provide a total of 4 MWh of energy (1 MW x 4 hours = 4 MWh).

Power capacity and energy storage look different for different technologies as shown in Figure 2.

Different applications of energy storage systems require systems with different power capacities and quantities of energy storage. In the following section, we look at the promising applications of Li-Ion that can be used to support the electric grid.

BESS INTEGRATION AND APPLICATION TO ELECTRIC GRIDS

BESS can be located within the *transmission network*, within the *distribution network*, or *co-located with energy generation* or an *end-user*. BESS co-located with end-users (e.g., BESS sited at a customer's facilities, a Power Wall® in a home, or an electric vehicle) may be connected to allow charging from the grid. Net-metered and distributed "smart-grid" systems would also allow BESS to discharge stored energy to the grid (typically requiring smart meters at each end-user-owned system).

9 Another helpful analogy is to think of a container of water as representing an energy storage system. In this case, the size of the container's spout represents the storage system's power capacity while the volume of the entire container represents the maximum energy that can be stored in the system.

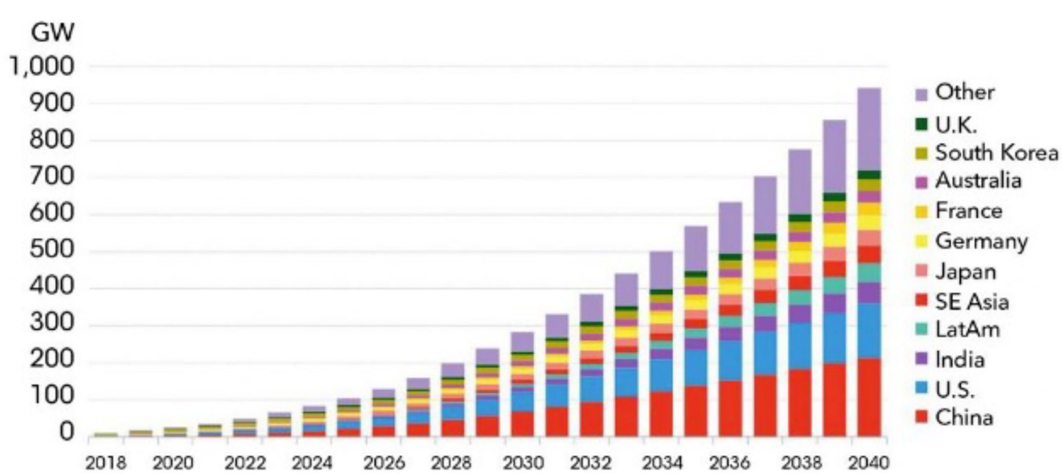

Figure 1 – Global cumulative storage deployment of Li-Ion 2018–2040

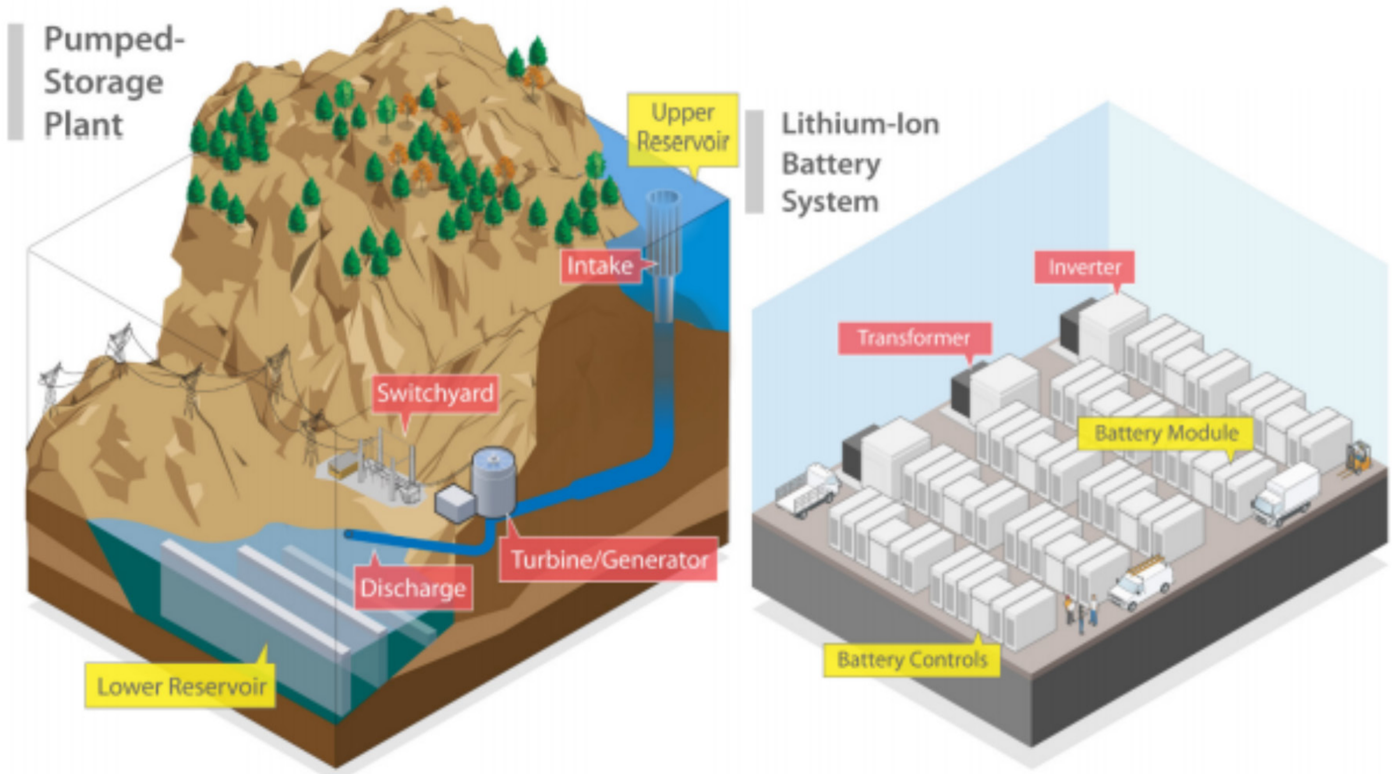

Figure 2 – Power capacity (in red) and energy storage (in yellow) for pumped hydro and Lithium-Ion energy storage systems.
Source: Denholm et al, 2021.

Electricity markets can enable or hinder the expansion of BESS applications by allowing BESS to provide multiple services, stack multiple benefits, and receive payment for these various services. The regulatory landscape is shifting to enable greater BESS application.[10]

BENEFITS OF BESS APPLICATIONS

A dramatic reduction in the cost of utility-scale batteries is leading to increasing grid-integration of BESS, which are being added to electric grids to realize some combination of the following benefits:

- For *energy arbitrage* purposes (e.g., charging the battery at times when power prices are "low" such as at night and then dispatching it at times when power prices are higher)
- To provide *congestion relief* in transmission and/or distribution systems or defer the need for transmission system capacity upgrades
- *Ancillary services* to maintain grid reliability:
  - To provide regulating reserves and frequency regulation quick responses when spikes in demand occur
  - To enhance energy ramping (i.e., responding to rapid changes in demand) without requiring an "idling" level of operation (such as is required for thermal power generators)
  - To support automatic generation control[11] (i.e., maintenance of system frequency despite load variability to achieve optimal generation levels)
- To *shave peak demand* (i.e., substitute BESS for the use of peaking generators)
- To *mitigate the variability of renewable resources* (e.g., wind and solar)
- To *improve power quality* (e.g., where BESS is in or near load centers, or at end-user facilities)

10 EPRI, 2020. *Overview of Emissions Impacts from Grid-Connected Battery Energy Storage.* EPRI, Palo Alto, CA: 2020. 3002020074.

11 EPRI, 2019. *Strategic Intelligence Update: Energy Storage & Distributed Generation.* EPRI, Palo Alto, CA: 2019. 3002016339.

Typically the decision to integrate a BESS into a larger electric power system will not be based on a a single reason, but rather the pairing of multiple benefits conferred through a grid-integrated BESS (e.g., a power generator that relies upon a separate company for transmission and distribution may not receive any benefit from transmission congestion relief).[12, 13]

The sections below provide explanations of the some of the benefits listed above that BESS can provide in a power system, including ancillary services, shaving peak demand, and integrating variable renewable resources.

FREQUENCY REGULATION

A well-established use of BESS is to provide frequency regulation. This use includes BESS designed to meet regulating reserves, provide inertia responses, and fast frequency response typically provided through synchronous generation.[14] Due to the ability of batteries to rapidly charge and discharge, BESS provides an option for meeting these system needs and potentially reducing the high cost of providing these services. Additionally, as shown by Figure 3, the fast-ramping ability of BESS can reduce the operating costs of equipment idling in preparation to meet spikes in demand as well as the ability to rapidly absorb electricity supplied beyond the prevailing load.

12 NREL, 2019. Utility Scale Battery Storage: Where, when, why, and how much? Greening the Grid Webinar by Paul Denholm. Presented February 27th, 2019. Available: https://greeningthegrid.org/trainings-1/webinars/utility-scale-battery-storage-when-where-why-and-how-much Bistline, et al. (2020). "Energy storage in long-term system models: a review of considerations, best practices, and research needs," Progress in Energy 2(3). Available: https://iopscience.iop.org/article/10.1088/2516-1083/ab9894/meta

13 Bistline, et al. (2020). "Energy storage in long-term system models: a review of considerations, best practices, and research needs," Progress in Energy 2(3).

14 Ibid.

CAPACITY TO MEET PEAK LOAD / PEAK SHAVING

Another growing use of BESS is to displace the need to operate existing "peaking" capacity generators (e.g., natural gas combustion turbines) and/or to replace existing peaking capacity that may retire. This BESS application requires a system that provides peaking capacity with energy storage to match the characteristics of the load peak(s) for the region served.

For example, one hour of energy storage potentially could fulfill the peak capacity load for a region for one hour. The energy storage required will vary based upon the peaking dynamics of the region – for instance regions with peaks that experience increases and decreases in demand, but over a short amount of time (e.g., <4 hours in Florida) may require fewer hours of energy storage, and therefore smaller and less expensive BESS. Other regions with more gradual but longer-lasting peaks (e.g., ~6 hours in New York) would require additional energy storage to match the longer peak and therefore larger and more expensive BESS.[15] As shown in Figure 4, BESS can limit the operational time of mid-merit and peak generators thereby reducing generation by less economic, and higher emitting, generating units.

15 Ibid.

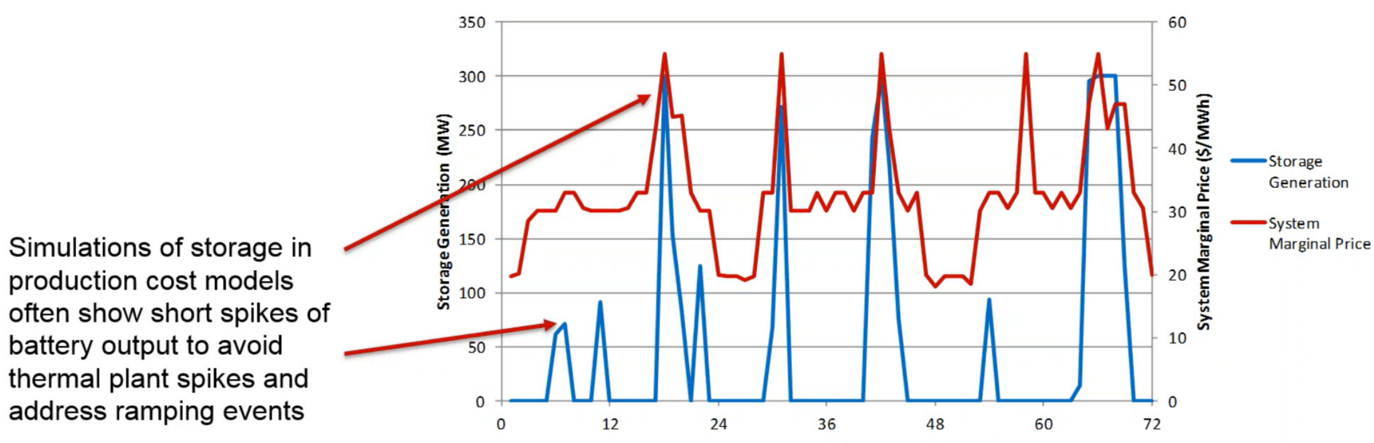

Figure 3 – Ramping benefit from BESS – comparing storage power generation to system marginal price. Source: Denholm, 2019.

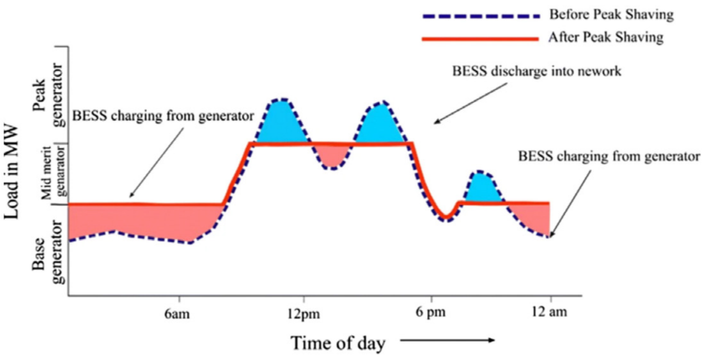

Figure 4 – The benefit of BESS to shave peak demand and absorb excess generation thereby reducing peak generator's operation. Source: Uddin et al, 2018.

INTEGRATION OF RENEWABLE RESOURCES AND BESS

A key BESS application that may reduce GHG emissions is co-locating BESS with variable renewable energy generation. This can be used to reduce the cost of transmission to connect the system into the grid and be used to shave peak load.[16] Energy generated by the variable renewable generator that cannot be dispatched to the power system can be stored in the BESS and injected into the grid during variable generation down-times. BESS can help to enable the connection of variable sources of renewable energy to the grid by absorbing generation beyond the prevailing load or the transmission system's maximum capacity and discharging stored energy later when it can be utilized more effectively.

There is an interesting dynamic related to the variability of solar energy production that can impact peak demand in a grid region, and as a result may expand the potential applications for BESS. Significant deployment of solar PV resources in a region can improve the conditions to adopt BESS by pushing peak demand later into the day (i.e., early evening) and narrowing the peak demand period. In many regions of the U.S., peak electricity demand typically spans the late afternoon and early evening and is driven by air conditioning and other loads. This period often corresponds to the same period when solar PV systems are operating near or at full capacity. Due to the overlap of peak electricity demand and solar PV's timing for full capacity generation, solar PV systems reduce the amount of electricity that must be supplied to meet the so-called "net" peak load. Figure 5 illustrates the peak narrowing effect of adding solar PV capacity to an illustrative power grid at 0%, 5%, 10%, 15%, and 20% of overall system load (i.e., demand). BESS adopted in grids with significant deployment of solar PV resources can support further reduction in the operational time of peak generators.[17]

As shown in Figure 5, the "net" peak period occurs later in the day and is narrower as solar PV deployment increases from 0% to 20%. The addition of solar PV generation at or above 10% of the total grid load can significantly narrow the timing of the "net" peak of energy consumption, which reduces the storage capacity required to shave this peak demand.[18]

In addition to the BESS' capability to peak "shave," BESS also can "ramp" quickly up and down as described above in the Frequency Regulation section. This ability is helpful to integrate high levels of renewable generation into a power system. Because of the changing profile of the system peak as illustrated in Figure 5, it is important for the power system to be able to ramp up quickly in the late afternoon/early evening when solar resources go offline, but electricity demand is still high. As shown in Figure 5, as solar deployment in a power system increases, the steeper the morning trough and evening peak may become which requires generation facilities to more quickly ramp down and up respectively. As shown in Figure 3, BESS can ramp up and down virtually instantaneously which is an important benefit that BESS can provide in power systems.

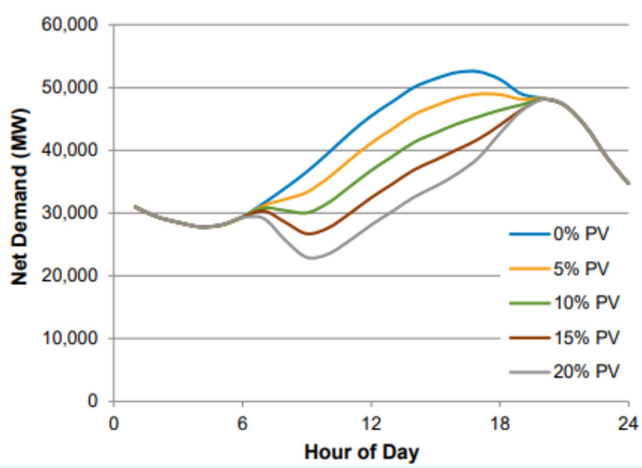

Figure 5 – How the proportion of the overall grid energy supplied by solar PV impacts peak demand

16 *DC-Coupled PV Plus Energy Storage Integration Technology Evaluation.* EPRI, Palo Alto, CA: 2017. 3002011891.

17 Bistline and Young (2019). "Economic drivers of wind and solar penetration in the US," Environmental Research Letters 14(12). Available: https://iopscience.iop.org/article/10.1088/1748-9326/ab4e2d/meta

18 Denholm and Margolis, 2017. Available: https://www.osti.gov/biblio/1376049

POWER QUALITY

Typically, it is challenging to site new power generation facilities near load centers due to air pollution, environmental justice, and not-in-my-backyard (NIMBY) concerns. BESS do not cause the same human health concerns as combustion-based generating facilities; however, nearby communities may be concerned about the possible safety risk of a BESS experiencing "thermal runaway."[19] The proximity of BESSs to load centers presents an opportunity to improve power quality and further reduce transmission congestion.[20] End-users that require reliable and high-quality power may co-locate BESS within their facilities to support operations.

The benefits achieved by using BESS will vary based on the context and local grid system factors. Tools and analyses like that provided by the EPRI Storage Value Estimation Tool (StorageVET[21]) can help decision-makers to evaluate where to place and install energy storage, optimum storage size, and storage controls appropriate for various options.

SUMMARY OF BESS LIFE CYCLE GHG EMISSIONS

Lithium-ion battery (LIB) technology is the most widely used battery chemistry in the United States and is the most relevant today to US-based electric utilities. This section presents the environmental life cycle considerations of LIB. The life cycle of BESS includes, "raw material provision, refining, production, assembly, transport, installation, operation, maintenance, disposal, and potential recycling."[22] Figure 6 presents the life cycle assessment (LCA) boundaries used in a recent EPRI analysis (EPRI 2019) that evaluated multiple LIB configurations and scenarios for BESS application.

LCA accounting and organizational GHG accounting (scopes 1, 2, 3) are different, but related approaches to calculating emissions. In the sections below we will present the aspects of the life cycle emissions within the organizational GHG accounting framework and from the perspective of electric companies.

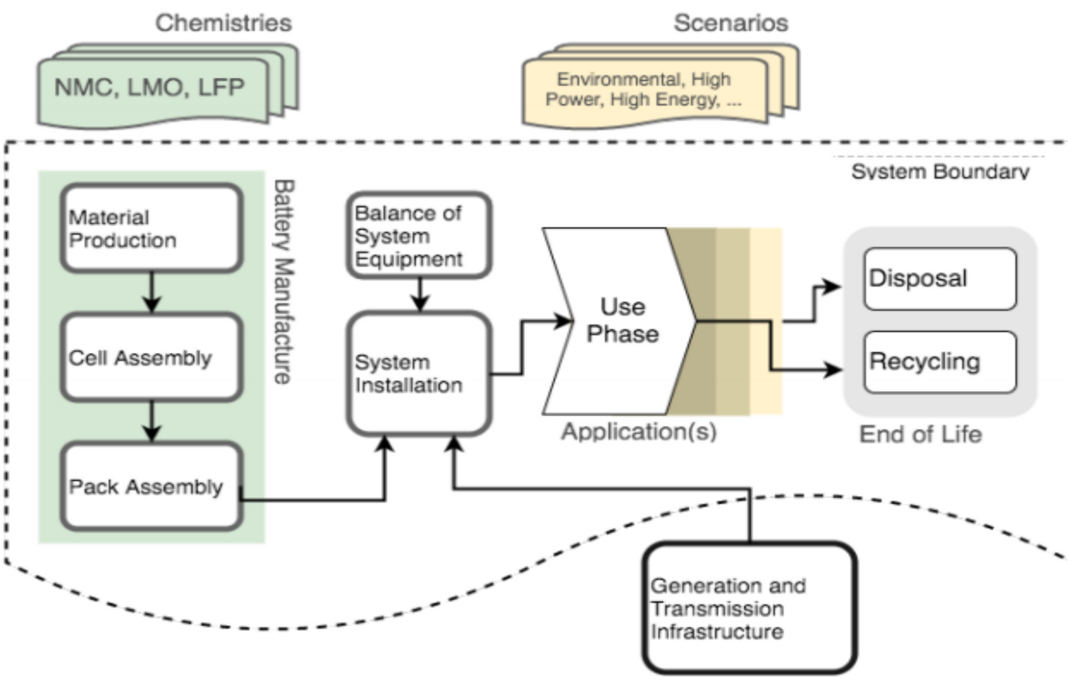

Figure 6 – The boundary for BESS LCA that identifies where differences in BESS chemistries (in green) and differences in BESS scenario applications (in yellow) will result in changes to life cycle emissions. Source: EPRI, 2019. In this figure, NMC refers to nickel-manganese-phosphate, LMO refers to lithium-manganese-oxide, and LFP refers to lithium-iron-phosphate.

19 In simple terms, thermal runaway begins when the heat generated within a battery exceeds the amount of heat dissipated to its surroundings. If this condition is not corrected, internal battery temperature may continue to rise, causing the battery to overheat potentially leading to a fire. The rise in temperature in a single battery may begin to affect other batteries that may be located nearby hence the use of the term "runaway."

20 NREL, 2019. Grid-Scale Battery Storage: Frequently Asked Questions. Greening the Grid, Grid Integration Toolkit. https://www.nrel.gov/docs/fy19osti/74426.pdf

21 StorageVET® 2.1 facilitates the understanding of where to place and install energy storage, the optimum size as well as controls options. StorageVET 2.1 implements dispatch optimization with sensitivity analysis to assist in planning energy storage project development by enabling rapid analysis of scenarios with different storage sizes, costs, and value streams. Additionally, StorageVET 2.1 is valuable as a research tool to inform broad-sweeping analyses of trends in storage value as a function of location, operation, and technical capabilities. StorageVET is a publicly available, open-source, Python-based energy storage valuation tool.

22 *Program on Technology Innovation: Life Cycle Assessment of Lithium-ion Batteries in Stationary Energy Storage Systems.* EPRI, Palo Alto, CA: 2019. 3002017000.

GHG ACCOUNTING FOR BESS

Adapting an LCA to an organizational GHG accounting approach is straightforward for battery manufacturing and system installation—which entail upstream scope 3 emissions for an electric company—and battery end-of life-impacts which are similarly downstream scope 3 emissions. The accounting of emissions associated with BESS operations, however, is more complicated as discussed below under Scope 2 emissions.

For GHG accounting, an important determinant to bear in mind is the location of the BESS in relation to the electrical meters. BESS may be "front of meter" (e.g., co-located with variable energy generation or hybrid generation units), "behind the meter" (i.e., co-located with an end-user), or "between meters" (i.e., as a component of the T&D system) as depicted in Figure 7.

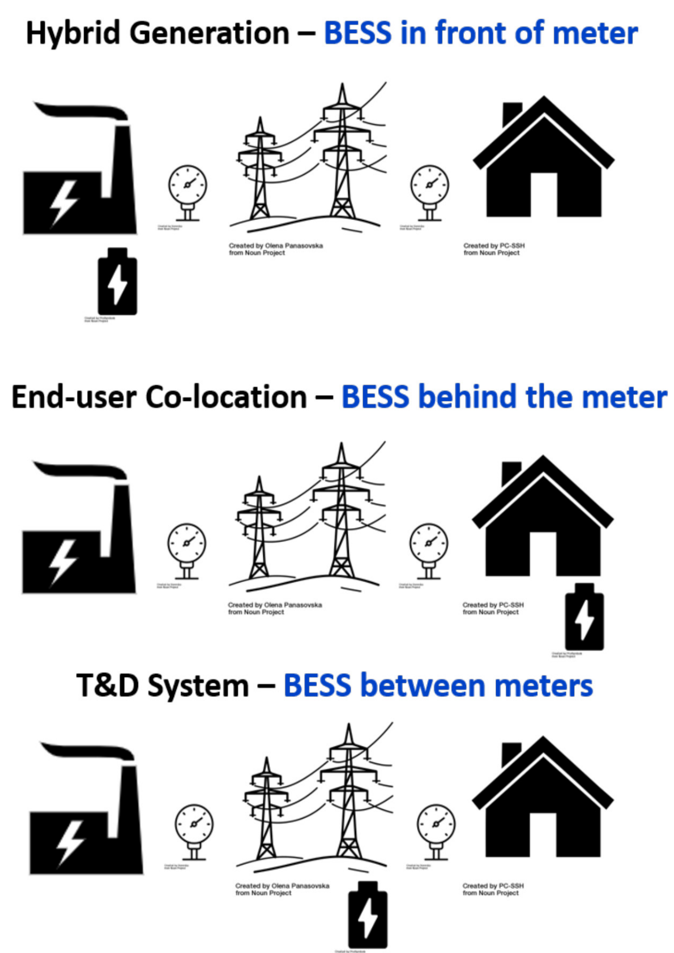

Figure 7 – Location of BESS in relation to electric grid meters

SCOPE 1 EMISSIONS

The scope 1 emissions that may result from the integration of BESS to support electric company operations are limited to any direct emissions related to the installation or maintenance of the equipment. For example, a possible source of scope 1 emissions could be those resulting from fuel combustion in company-owned or operated vehicles used to transport and install a BESS. These scope 1 emissions are likely to be accounted for by an electric company as part of their vehicle fleet emissions, rather than being accounted for separately for BESS.

SCOPE 2 EMISSIONS

Electricity generators report direct emissions from energy generation (scope 1) while transmission and distribution (T&D) only companies (i.e., "wires only" companies) report indirect emissions associated with T&D losses as scope 2. The result of integrating utility-scale BESS into grid systems is to increase the electric energy losses already accounted for associated with T&D "line losses."

BESS result in energy losses due to two factors:

(i) "Roundtrip efficiency losses" associated with charging and discharging batteries and battery thermal controls (i.e., system cooling), and

(ii) losses associated with battery self-discharge as the BESS awaits discharge to an external load.[23]

For example, when charging a 90Wh capacity battery you may need to input 100Wh and when discharging from that same battery you may only receive 80Wh due to inefficiencies that cause losses as shown in Figure 8. Batteries also leak a small amount of their stored electricity over time[24] as shown in Figure 8. Roundtrip efficiency is a much larger factor leading to energy losses from BESS than the self-discharge rate for Li-Ion systems.

Beyond the battery's roundtrip efficiency losses, the BESS and its application can influence the expected losses depending on how the BESS is integrated into the electrical grid. Inverters, transformers, and charge conversion from AC to DC or DC to AC may be necessary and each of these system components add to the loss factor. Typically, the AC-AC roundtrip efficiency will capture all BESS losses and be most relevant to the electric grid BESS applications.[25]

23 Ibid. EPRI 2019.

24 Li-Ion BESS have a low self-discharge rate that is typically 1-3% of stored energy, lost per month.

25 Ibid. NREL 2019.

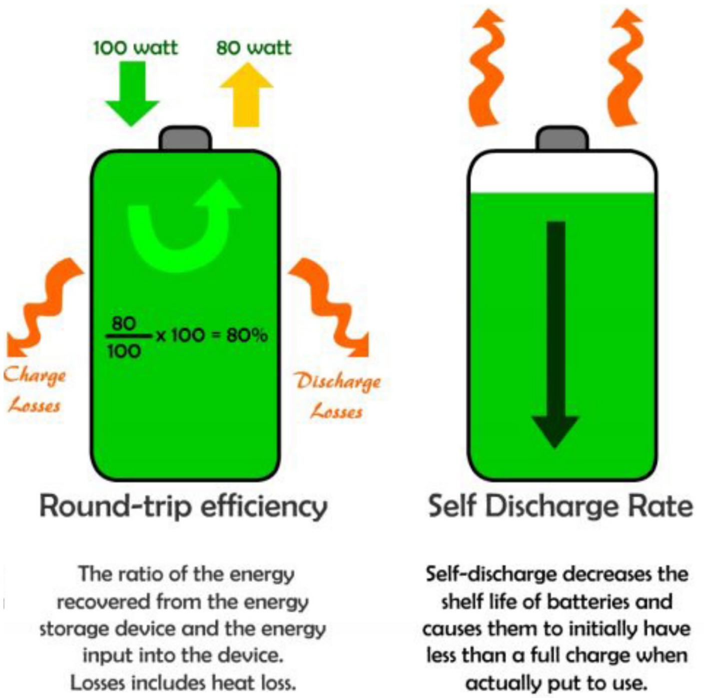

Figure 8 – Roundtrip efficiency and the self-discharge rate are two types of losses that should be factored into emission calculations. Source: Future Green Technology, 2018. The self-discharge rate is estimated to be ~1-3% per year.

Roundtrip efficiencies vary between 65% and 90% depending on the battery chemistry, the rate of cycling (i.e., the frequency of charging and discharging), the age of the battery, and the depth of discharge (i.e., the portion of storage capacity filled when charging or the portion of stored energy discharged when discharging).[26] It is important to consider how these performance-related BESS parameters may need to be updated over the system's lifetime. For example, degradation is a first-order driver of battery performance (and operations) and depends not only on the battery's age but also its operating history.[27]

26 Mongird K. et al, 2019. Energy Storage Technology and Cost Characterization Report. HydroWIRES U.S. Department of Energy. Available: https://www.energy.gov/sites/prod/files/2019/07/f65/Storage%20Cost%20and%20Performance%20Characterization%20Report_Final.pdf. McKay, Chris (2019). How three battery types work in grid-scale energy storage systems. Windpower Engineering and Development. Available: https://www.windpowerengineering.com/how-three-battery-types-work-in-grid-scale-energy-storage-systems/

27 EPRI, 2021c. *Incorporating Energy Storage Resources into Long-Term Capacity Planning Models: An Assessment of the Inclusion of Specific Features on Battery Deployment in the Southeastern United States.* EPRI, Palo Alto, CA: 2021. 3002021969.

For GHG accounting purposes, batteries may be considered components of the systems they support, whether it is a power generating unit (e.g., a photovoltaic facility), a T&D system, or a retail end-user (e.g., a Power Wall® in a home). In the case of a "wires only" T&D company that owns a battery integrated into their system, the "losses" associated with BESS roundtrip charge efficiency and self-discharge would be added as a component of the company's scope 2 emissions resulting from T&D losses from power transmitted or distributed to an end-user.

The same would be true for a vertically integrated electric company that transmits or distributes electricity generated by an external 3rd party entity (versus their generation); T&D losses from BESS would be categorized as scope 2. If the integrated electric company transmitted and/or distributed electricity generated by its owned powerplants, then any additional line losses from BESS would not result in indirect emissions as these emissions already would be captured under scope 1 for the company and so not separately calculated or reported under scope 2.

While these applications are consistent with the categorization of T&D line losses[28], batteries may be used in a variety of ways in modern power systems and some of these applications are not definitively defined by existing GHG accounting guidance. For example, accounting for the GHG emissions associated with end-user-owned BESS utilized in a "smart-grid" system[29] is still an open question. The losses from end-user-owned BESS potentially could be counted as indirect emissions from the T&D system (and appear in the electric company's GHG inventory), or these indirect emissions from battery losses could be assigned to the end-user's scope 2 GHG inventory. The professional GHG accounting community has not yet coalesced around a definitive categorization for end-user-owned BESS losses within a smart grid.

Table 1 addresses whether to include BESS losses in electric company GHG inventories and how to categorize any indirect emissions associated with these losses by scope. Each row presents the perspective of the type of entity reporting its GHG inventory, the location of the BESS in relation to the grid, and the emissions scope categorization for the scenario.

28 EPRI, 2021b. *Greenhouse Gas Emissions Accounting for Electric Companies: A Compendium of Technical Briefing Papers and Frequently Asked Questions.* EPRI, Palo Alto, CA: 2021. 3002022366.

29 A smart grid system facilitates end-user owned BESS to both charge from and discharge to households to provide electricity and support grid function. Generally, compensation is provided to the end-user in the latter case.

Table 1 – T&D-related GHG Emissions Accounting for BESS by Type of Electric Company and BESS Location

Electric Company Corporate Structure	BESS Location	Does the GHG Inventory include BESS losses? Which scope?
Vertically Integrated Electric Company	Component of an integrated grid system	**No** – Emissions from self-generated power are scope 1. All emissions are accounted for and T&D losses are not indirect for the company. **Yes** – (exception to above) for wholesale power purchased from other generators and transmitted and/or distributed across the company's T&D system. If purchased for delivery to end-users these emissions are scope 3). If purchased for delivery to other intermediaries or load serving entities (LSEs) these emissions are scope 2.
	External to integrated grid system:	
	Upstream power generator	**No** – Wholesale power purchased from other generators that is transmitted and/or distributed (e.g., wheeled) across the company's T&D system will be incorporated into the emission factor (e.g., tonnes CO_2e/MWh) associated with the purchased power and therefore will already be accounted for within scope 2 calculations.
	Downstream end-user[30]	**No** – Emissions are already accounted for under the company's existing scope 1 and/or scope 2 reporting (see Distributed Grid section for more information).
Generation and Transmission Cooperative (G&T)	Component of G&T Co-op	See answer for Vertically Integrated Electric Company "Component of integrated grid system" above. The only distinction is that BESS losses are limited to the bulk transmission system unless the G&T co-op also owns the local distribution system(s).
	External to G&T grid system:	
	Upstream power generator	See answers for Vertically Integrated Electric Company: "External to integrated grid system" for "Upstream power generator" and "Downstream end-user" above.
	Downstream end-user	
Transmission and/or Distribution (T&D) Company	Component of the T&D system	**Yes** – the inventory would include indirect GHGs associated with BESS T&D losses, which would increase the overall loss factor for the T&D system; categorized as scope 2.
	Upstream of the T&D system	**No** – BESS losses occur before power is metered and injected into its T&D system. BESS losses will be incorporated into the emission factor associated with the purchased power and therefore will already be accounted for within scope 2 calculation.
Independent Power Producer (IPP)	Component of the generation system	**No** – Emission from self-generated power is scope 1. Emissions are not indirect for a generator.
	Component of the T&D system	**No** – Emissions are already accounted for in scope 1 and T&D losses are not indirect for a generator.

30 End-user located BESS are considered to be entirely separate from the grid (e.g., a Power Wall® or electric vehicle that is "behind the meter" and provides power to the end-user exclusively). The scenario that incorporates end-user owned BESS in a smart-grid scenario is discussed in the section titled "Distributed Smart-Grid Scenario."

SCOPE 3 UPSTREAM EMISSIONS

Scope 3 emissions result from the component materials, battery production, and installation when performed by an external entity. Upstream indirect emissions result from the production of the materials within the battery cells (lithium in addition to various metals and plastics), component manufacturing, and assembly processes. Ideally, battery manufacturers could provide GHG emissions information based upon the battery cell materials and production processes specific to the relevant BESS chemistry and application, but this information may not be available.

Component Material Emissions

If the manufacturer information is not available, estimates of battery chemical mass balance are available in existing LCA databases. Table 3-1, 3-2, and 3-3 in EPRI's 2019 LCA report[31] may help identify an appropriate value for estimating BESS material mass balances that can be paired with emission factors (EF) for each material from the EcoInvent Database to estimate emissions or the EPA Waste Reduction Model (WARM) Documentation for GHG emissions.[32, 33] With emission factors for each material, and the mass

31 Available online https://www.epri.com/research/products/000000003002017000.

32 Available https://www.ecoinvent.org/database/ecoinvent-33/ecoinvent-33.html

33 If the desired battery chemistry is not included in these tables, the Argonne National Laboratory's Battery Performance and Cost Model (BatPaC 3.0) tool also can be used to identify battery mass balance.

balance identifying the quantity of each material in the BESS, one must multiply the mass quantity of each material by the EF for that material, applying Equation 1, and then sum the emissions from all components to calculate the total emissions of the BESS applying Equation 2.

Equation 1: calculation of a BESS component material emissions

BESS component #1 emissions = Mass of component material × EF for component material

Repeat the above equation for each component material (e.g., component 2, component 3)

Equation 2: calculation of total BESS components emissions

Total BESS components emissions = BESS component #1 emissions + BESS component #2 emissions + BESS component #3 emissions + BESS component #4 emissions (continue as needed)

Sample Calculation:

Applying Equation 1 for a simplified example system that includes just two components lithium cobalt oxide and nickel:[34]

> BESS component #1 emissions (lithium cobalt oxide): 1 short ton of virgin lithium cobalt oxide x 1.76 (tCO_2e/short ton) = 1.76 tCO_2e
>
> BESS component #2 emissions (nickel): 1.5 short tons of virgin nickel x 6.88 (tCO_2e/short ton) = 10.32 tCO_2e

Applying Equation 2 for this system:

> 1.76 tCO2e (emissions from lithium cobalt oxide – component #1) + 10.32 tCO_2e (emissions from nickel – component #2) = 12.08 tCO_2e Total BESS components emissions

Production Emissions

Battery production requires electricity, which can cause production emissions if generated through the combustion of fuel (e.g., natural gas). A literature review indicates that it requires between 18 and 760 kWh of electricity to produce each kWh of battery energy storage, while the EPRI 2019 report identifies a value range that falls in the middle of this literature review range at 37 to 72 kWh per kWh of battery energy storage.

34 Emission factors used in this sample calculation come from the U.S. EPA's Documentation for Greenhouse Gas Emissions and Energy Factors Used in the Waste Reduction Model (WARM), 2020. Available: https://www.epa.gov/sites/production/files/2020-12/documents/warm_electronics_v15_10-29-2020.pdf

BESS upstream emissions will vary based upon the power capacity (kW) and energy storage (kWh) of the system. Both system components are associated with emissions and different applications of BESS will require different combinations of power capacity and energy storage. To calculate upstream scope 3 emissions associated with battery production, one multiplies the activity data (either kW of power capacity or kWh of energy storage) by the amount of energy (kWh) required to manufacture a unit of BESS and applies an appropriate grid emission factor (EF) (CO_2e/kWh) for electricity generation in the location of the production factory as shown in Equation 3.

Equation 3: calculation of BESS production emissions

BESS production emissions = Activity data (kW if power capacity; or kWh if energy storage) × production electricity per unit of BESS (units must match activity data: either kW or kWh) × EF for production electricity

Sample Calculation:

> Applying Equation 3 for a 20 MWh BESS system produced in California:[35]
>
> 20,000 kWh system capacity × 72.13 kWh/kWh of capacity × 0.00022621 tCO_2e/kWh = 326.33 tCO_2e

A grid-specific EF, such as eGRID's regional grid average EFs, can be applied to Equation 3. Or, if the electricity used is supplied by onsite fossil fuel generation or onsite renewables then a more specific emissions factor could be applied.

The EPRI 2019 study estimates that, on average, utility-scale battery production emits 254.6kg CO_2e per kW installed based upon the 11 BESS installations evaluated in California.[36] If applying this EPRI 2019 EF to calculate BESS emissions, you should justify the appropriateness of the EF and scenario design to the BESS system in question.

35 Emission factors used in sample calculation come from EPRI 2019 Table 3-4 (high assembly energy inputs) and eGRID sub grid region value for CAMX.

36 Ibid. EPRI 2019.

Installation Emissions

Beyond BESS production emissions, some emissions occur through the installation of BESS. Emissions may result from fuel combustion within vehicles and/or machinery used to transport and install a BESS. These emissions may be calculated by tracking or estimating the quantity of fuel used and applying an appropriate EF.

SCOPE 3 DOWNSTREAM EMISSIONS

Scope 3 downstream emissions are associated with the end-of-life phase of BESS. Utility-scale BESSs are typically disassembled to the cell level with metals and plastics (Figure 9) recovered through recycling pathways or discarded as waste (EPRI 2019). Currently, the market for lithium-ion battery recovery in the United States is nascent, and batteries are only smelted for plastic and/or metal resource recovery in select locations in the United States before being shipped to Canadian or European facilities that recover the lithium components.[37]

In the United States, lithium-ion battery disposal is governed by hazardous waste regulations, and end-of-life emission estimations assume legal and proper disposal.[38] Emissions associated with waste management transportation involved in moving modules between independent locations for disassembly, resource recovery, and lithium recovery can be accounted for as scope 3 emissions by an electric company.

37 Ibid.

38 EPRI, 2021a. *End-of-Life Management for Lithium Ion Battery Storage: Issues, Uncertainties, and Opportunities.* EPRI, Palo Alto, CA: 2021. 3002019572.

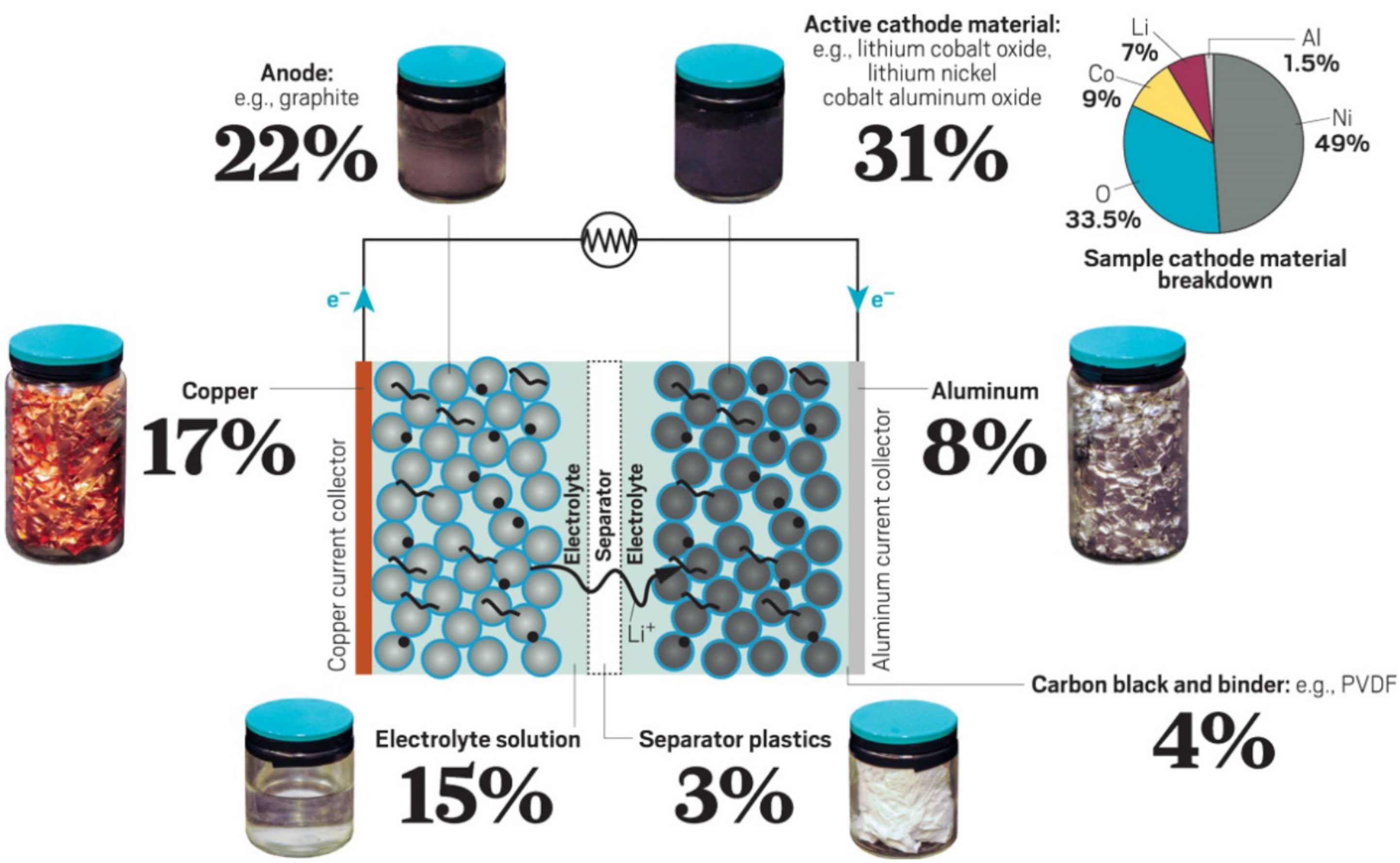

Figure 9 – Sample material components for Li-Ion batteries. Source: Jacoby, 2019.

DISTRIBUTED SMART-GRID SCENARIO

Although GHG accounting for "smart-grid" scenarios is not yet settled, we offer the following discussion for consideration. In a smart grid in which end-user-owned BESS both provides electricity to the grid and charges from the grid, the actual quantity of electricity delivered to the grid by the BESS needs to be tracked. Electric companies may need to apply an appropriate loss factor to electricity purchased from the smart-grid "end-users" to capture the indirect emissions associated with losses from BESS AC-AC roundtrip charge efficiency and self-discharge. In this context, "end-users" within a smart grid are both consuming electricity and playing the additional role of providing the use of their BESS to supply the grid with BESS-stored electricity. From an accounting perspective, the energy delivered back to the grid from these end-users with BESS would need to be tracked separately from electricity consumed by the end-user and an appropriate loss factor applied to the BESS-stored electricity that is fed back into the grid.

There is the potential for calculating double losses here. Electric companies feed energy into these end-user batteries and some of that same electricity goes back through distribution lines when power is "returned" to the grid. Line losses occur through both trips, from the original generator via the grid to the end-user and then back through a portion of the grid to a separate end-user. A "conservative" approach to address this would be to assess line losses for these scenarios equivalent to double the relevant grid-line loss factor, in addition to factoring in AC-AC efficiency related to the end-user battery charging and discharging. This is shown in Equation 4.

Equation 4: estimating line losses for electricity stored in end-user-owned BESS that is redistributed through the grid to reach consuming end-users (i.e., a distributed smart-grid scenario)

$$\text{Total line losses} = ((2 \times \text{grid-line loss factor}) + \text{AC to AC efficiency}) \times \text{kWh delivered to the end-user}$$

CONCLUSION

The guidance presented here for electric companies to calculate the GHG emissions from BESS integrated into the electric power grid is consistent with the treatment of T&D system line losses, which is well established within existing GHG accounting frameworks. When BESS is integrated into an electric grid, the T&D line loss factor needs to be adjusted to reflect the roundtrip efficiency and self-discharge losses that result from BESS. The line loss factor should be updated on a routine basis as electric companies incorporate more BESS resources into the power system.

APPENDIX A – GHG EMISSIONS SOURCES BY SCOPE FOR THE ELECTRIC SECTOR

Energy Sector	Scope 1 Emission Sources	Scope 2 Emission Sources	Scope 3 Emission Sources
Energy Generation	Stationary combustion at electricity generating facilities: • Boilers and turbines used in the production of electricity, heat or steam • Fuel pumps • Fuel cells • Flaring Mobile combustion: • Transportation of fuel by company-owned vehicles Fugitive emissions: • CH4 leakage from transmission and storage facilities • HFC emissions from LPG storage facilities • SF6 emissions from transmission and distribution equipment Physical or chemical processing • SO_2 scrubbers	Stationary combustion: • Emissions associated with electricity, heat, or steam purchased for use by an entity. • Consumption of electricity during transmission and distribution	Purchased power for resale Stationary combustion: • Mining and extraction of fuels • Energy for refining or processing fuels • Process emissions Production of fuels • SF_6 emissions Mobile combustion: • Transportation of fuels/waste • Employee business travel • Employee commuting Fugitive emissions: • Landfill waste decomposition • Pipelines • SF_6 emissions

Source: Adapted from Appendix D of the WRI Corporate Standard.

APPENDIX B – REFERENCES

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