BayWa r.e.

How Battery Operation affects the Cost of Storage

Techno-economic Analysis

Dina Jaber – BayWa r.e. Solar Projects GmbH

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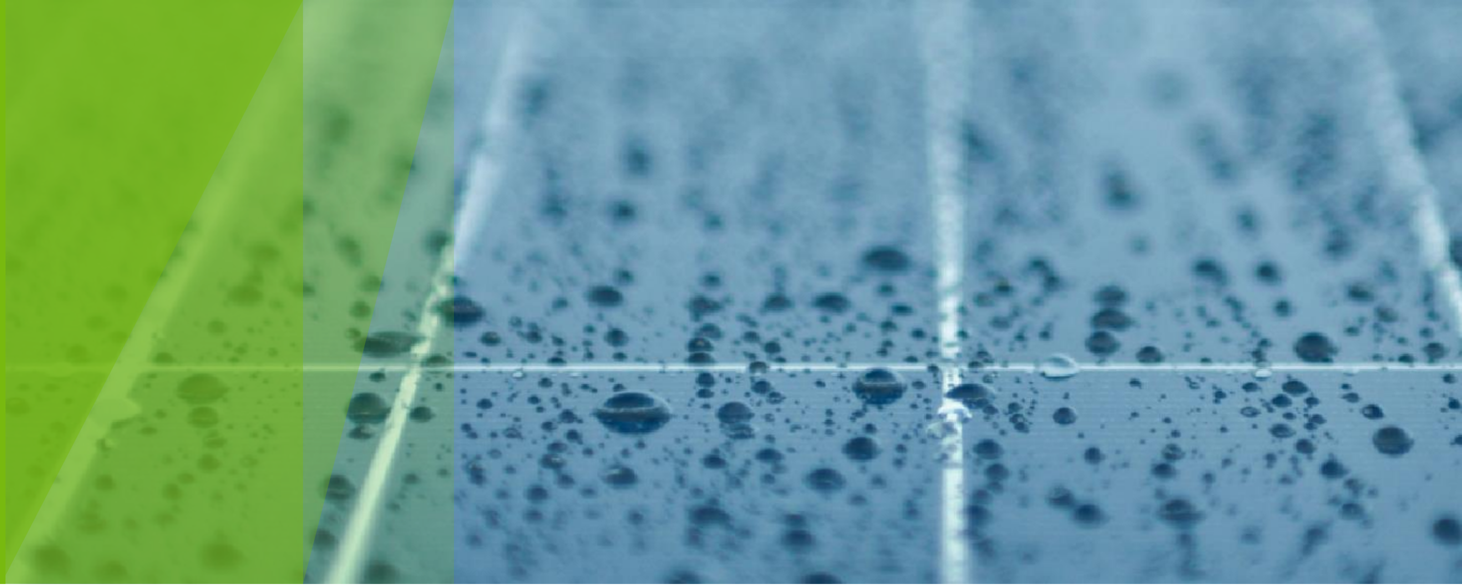

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Motivation

- Exploring the potential of battery storage system as a technical system optimizer and a revenue optimizer
- Analyzing the effect of operation and integration level ***(technical)*** on the economics of the project during its lifetime ***(economical).***
  - Integration level (AC-MV, AC-LV, DC)
  - Operation modes (cycles/day, degradation)
  - Capacity maintenance strategies (augmentation/replacement)
- $$\textit{Cost of Storage} = \frac{\textit{CAPEX+NPV OPEX+NPV Capacity Maintenance}\ [€]}{\varepsilon\ (\textit{Discharged Energy during Project Lifetime})[kWh]}$$

Utility Battery Storage System Designer

Project Definition

- Battery Chemistry and Operation
- Battery Size & Integration Level
- Project Lifetime
- Project Economics

Calculation

- Battery Degradation
- Battery Prices & Forecast
- Operation and Maintenance costs

Output

- Project Costs
- Cost of Storage
- Area Footprint

▼ Input Parameters

Technical Specifications	
Battery Chemistry	LFP-2
Battery Chemistry for Calculations	LFP
Battery Power (kW)	30,000
Storage Duration	1.0
Useable Battery Capacity BOL initial (kWh)	30,000
Useable Battery Capacity BOL incl Oversize (kWh)	30,000
Installed Battery Capacity BOL (%)	19%
Installed Battery Capacity BOL (kWh)	35,566
C-Rate	1.0

Technical Operation	
Equivalent 100% DOD Cycles / day	1.0
Equivalent 100% DOD Cycles / year	365
BOL Oversizing	0%
Replacement Capacity	60%

Project Specifications	
Battery System Connection	PV + Battery
Integration Level	AC LV

▼ Augmentation

BOL Oversizing	0%
Replacement Capacity	60%
Battery Type	LFP-2
Throughput(kWh/kWh)	365
Installed Battery Capacit	19%
Equivalent Cycle	425
New Cycle	313

Overview

Augmentations	Year	%
1	2028	15%
2		
3		
4		
Replacements	**Year**	**%**
1	2051	100%
2		
3		
4		

Year	Cummulated Cycles over years	F. Capacity	Capacity till Replacement	Warranty	Useable Capacity Initial	Augmentation	Useable Capacity + Augmentation
0	365	100.00%	100.00%	100.00%	100.0%		100.0%
1	730	93.85%	93.85%	93.20%	93.8%		93.8%
2	1,095	91.22%	91.22%	90.25%	91.2%		91.2%
3	1,460	89.26%	89.26%	87.96%	89.3%		89.3%
4	1,825	87.59%	87.59%	86.02%	87.6%		87.6%
5	2,190	85.80%	85.80%	84.30%	85.8%	15%	100.8%
6	2,555	84.29%	84.29%	82.74%	84.3%		98.4%
7	2,920	82.95%	82.95%	81.29%	83.0%		96.6%
8	3,285	81.75%	81.75%	79.95%	81.7%		95.1%
9	3,650	80.64%	80.64%	78.68%	80.6%		93.8%
10	4,015	79.62%	79.62%	77.48%	79.6%		92.5%
11	4,380	78.65%	78.65%	76.34%	78.6%		91.3%
12	4,745	77.71%	77.71%	75.24%	77.7%		90.1%
13	5,110	76.77%	76.77%	74.19%	76.8%		89.0%
14	5,475	75.82%	75.82%	73.18%	75.8%		87.9%
15	5,840	74.83%	74.83%	72.20%	74.8%		86.8%

▼ Net Present Costs Calculation — Discount Rate 2.5%

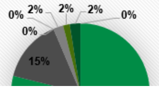
Euro

	0	1	2	3	4	5
Year	2023	2024	2025	2026	2027	2028
Initial CAPEX	10,306,911	-	-	-	-	-
OPEX initial	-	171,024	171,024	171,024	171,024	171,024
Augmentation System Costs	-	-	-	-	-	922,100
Additional OPEX for Augmentation	-	-	-	-	-	12,827
Total OPEX (incl Aug. OPEX)	-	171,024	171,024	171,024	171,024	183,851
Replacements System Costs	-	-	-	-	-	-
Warranty	-	219,277	219,277	219,277	219,277	219,277
Total	10,306,911	390,301	390,301	390,301	390,301	1,325,228
Yearly OPEX NPV	-	166,853	162,783	158,813	154,940	162,498
Yearly Augment. NPV	-	-	-	-	-	815,002
Yearly Replacements NPV	-	-	-	-	-	-
Yearly Warranty NPV	-	213,929	208,711	203,621	198,654	193,809
Yearly Costs Total NPV	-	380,782	371,494	362,434	353,594	1,171,308
NPV Running Costs total	11,582,051					
Yearly Available Battery Capacity	10,950,000	10,276,434	9,989,052	9,774,048	9,591,268	11,037,107

NPC total 21,888,961 €

Cost of Storage 74.74 €/MWh

System Cost CAPEX



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- Other tools were also used such as Homer Pro for Energy Flow Analyses and BayWa r.e. Investment Model for economical evaluation.

Methodology – Utility Battery Storage System Designer

Cycles/day & Battery Capacity

Application and Operation

Augmentation / Replacement

Degradation Curve

Costs / CAPEX

AC-MV / AC-LV / DC

OPEX

Maintenance/Insurance/ Warranty

NPV Project Costs

Oversizing VS Augmentation VS Replacements

➢ **Cost of Storage**

$$= \frac{CAPEX + NPV\ OPEX + NPV\ Replacement\ Costs\ [€]}{\varepsilon\ (Discharged\ Energy\ during\ Project\ Lifetime)[kWh]}$$

Assumptions and Simplifications

- Battery chemistry is **Lithium-Ion LFP**
- Project lifetime is 30 yrs and year of procurement is **2023**
- Discount rate = 2.5%
- Battery charging costs not considered: **theoretical scenario** where **charging is free**
- **Auxiliary consumption is neglected**, operation temperature is assumed to be kept at **nominal temperature**
- **One cycle** is one full charge and discharge cycle
- Battery is able to operate for **30 years**
- **AC-MV** integration level
- System power rating is 30 MW, battery capacities are 30 MWh, 45 MWh, and 60 MWh
- Warranty, insurance, and **OPEX** are assumed to be **constant** over the project lifetime
- Revenue optimizer costs, disposal costs, and recycling costs not considered

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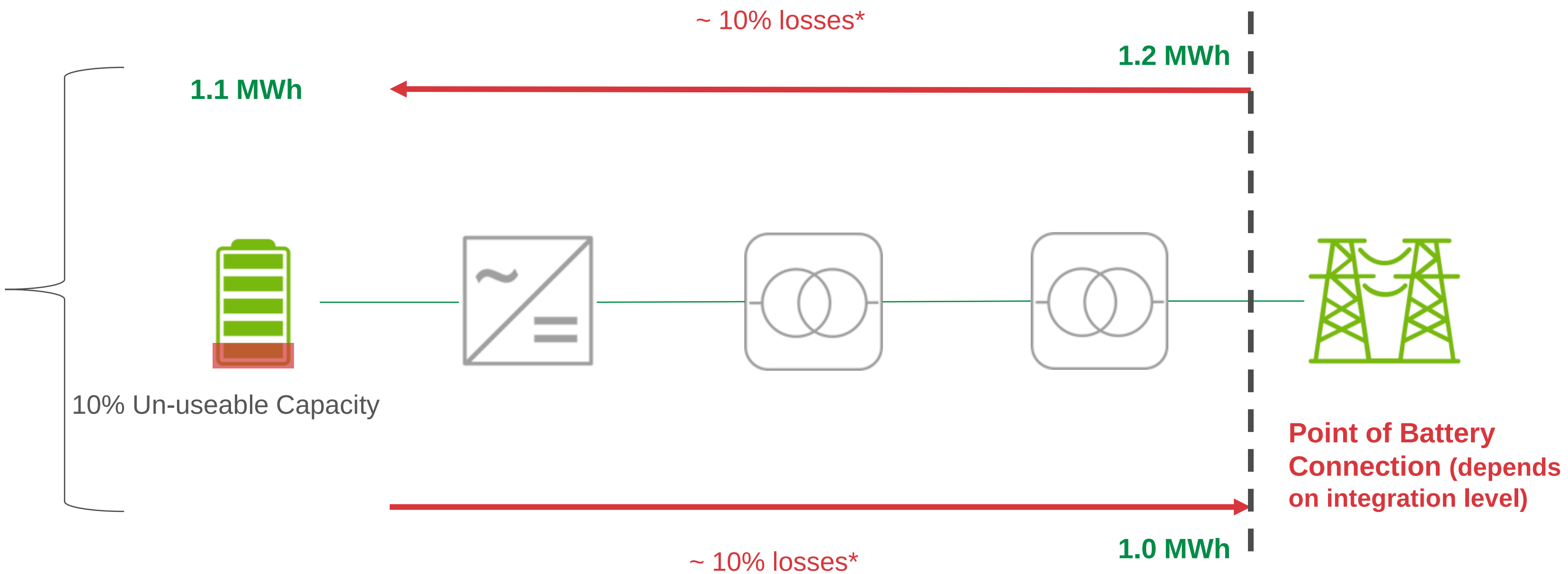
Capacity Definitions to Discharge 1 MWh

- Charging Capacity= 1.2 MWh

COS is only applied for discharing; battery charging costs not considered. Theoretical scenario where charging is free.



- Installed Capacity = 1.2 MWh

Installed Capacity to store 1.1 MWh should be 1.2 MWh to account for the 10% Un-useable Capacity.

- Useable Capacity = 1 MWh

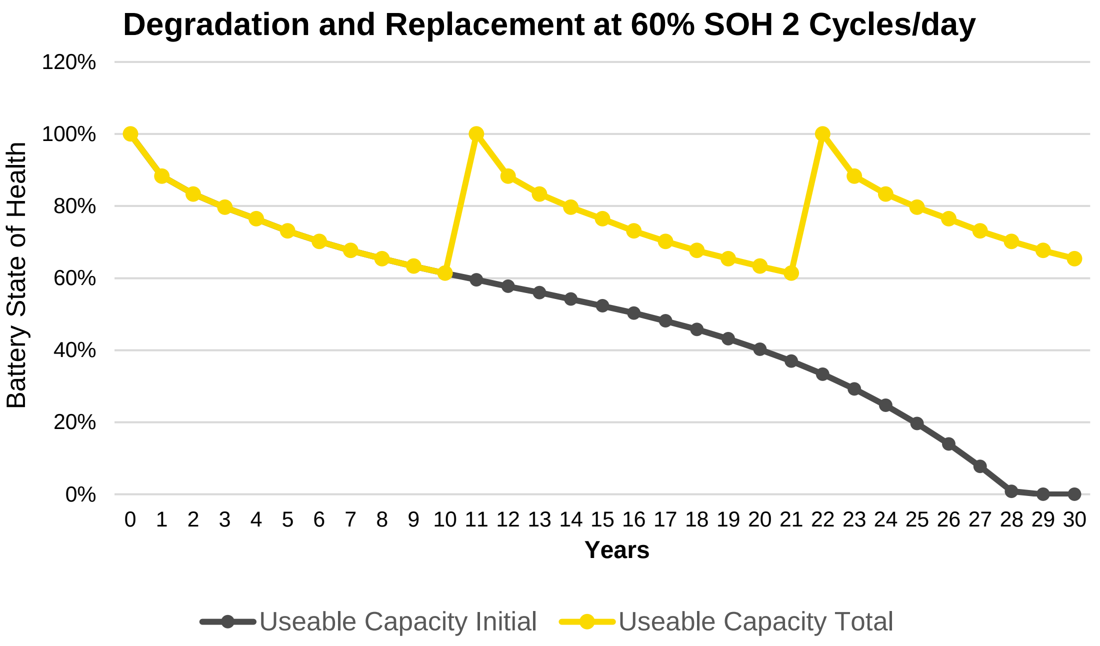
Capacity Maintenance Strategies

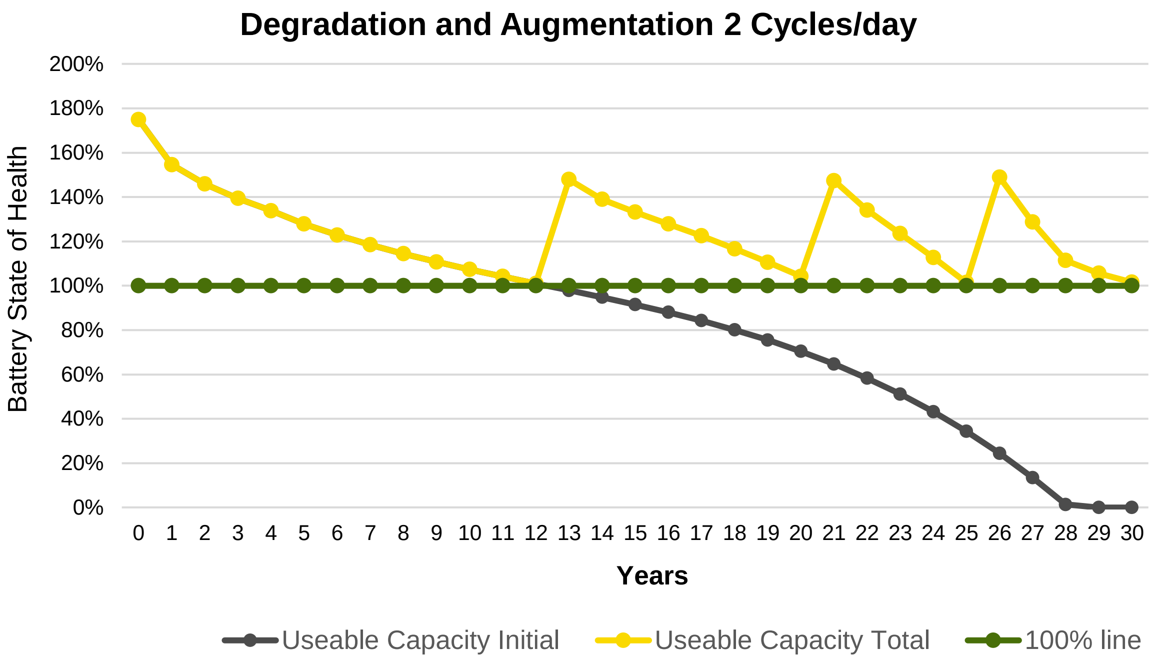
Replacement Strategy

- **Battery modules within battery containers are replaced when the SOH reaches a defined threshold, e.g. 60% SOH**
- **No extra area needed, as no additional components are installed**

Augmentation Strategy

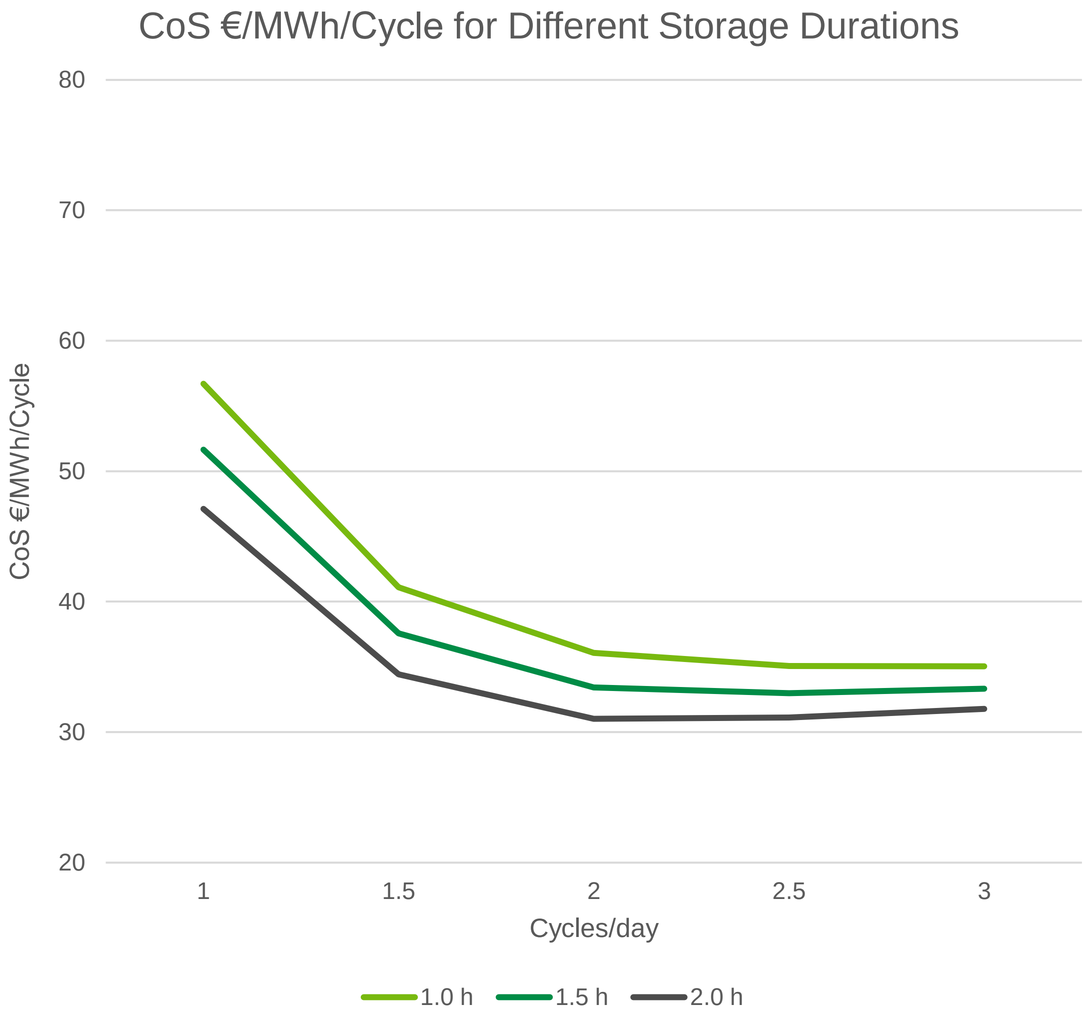
- **Done by adding incremental battery capacity to the project**
- **Usually defined by the grid operator and/or local legal regulations**





75% BOL Oversizing, 50% - 50% - 60%

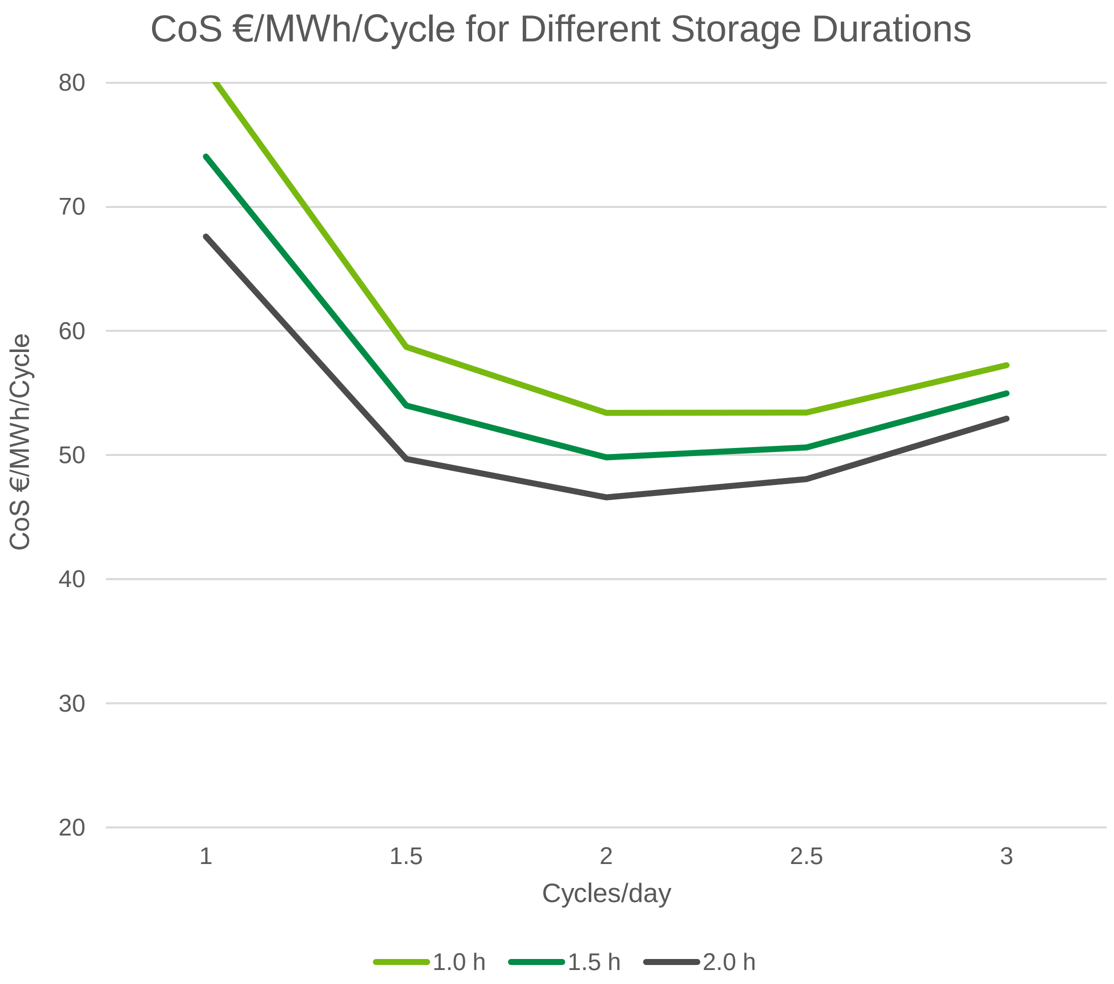
Cost of Storage – Replacement at 60% SOH



➢ *30 years project lifetime*

- **In general, the more the battery is operated, the sooner the replacement capacity is reached and the battery racks have to be replaced.**
- **At 3 Cycles/day the replacement costs start to dominate the cost of storage and the costs start to rise again.**
- **There is a decline in the battery system price until 2.5 Cycles per day, but the drop from 2 Cycles/day to 2.5 is minor.**
- **The design question for this specific case would then be: is the UK spot market volatile enough to allow operating the battery at 2.5 Cycles per day? If no > maximum economic cycling is 2 Cycles per day.**

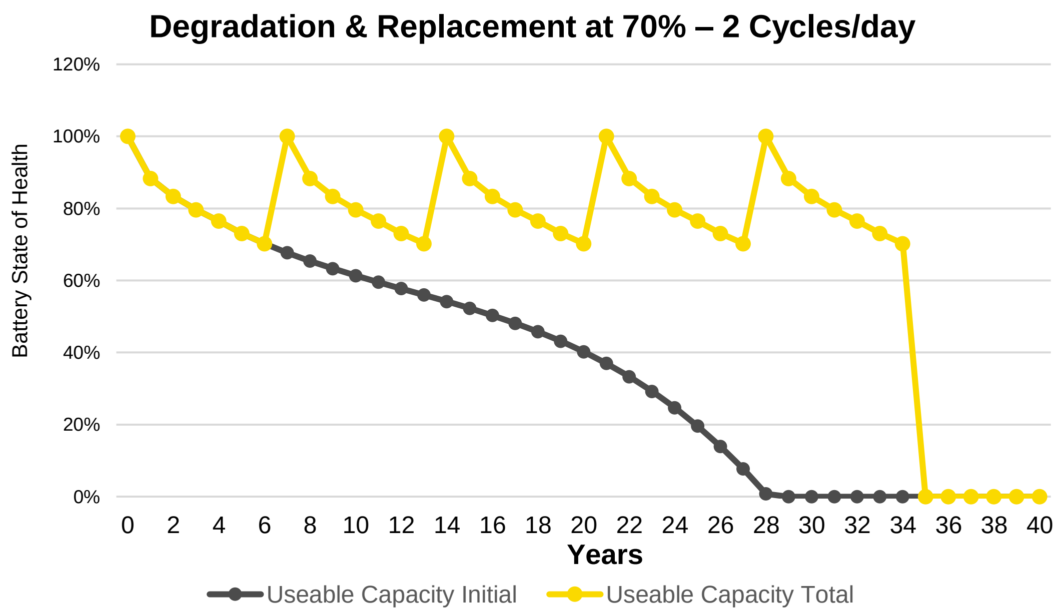
Cost of Storage – Replacement at 70% SOH



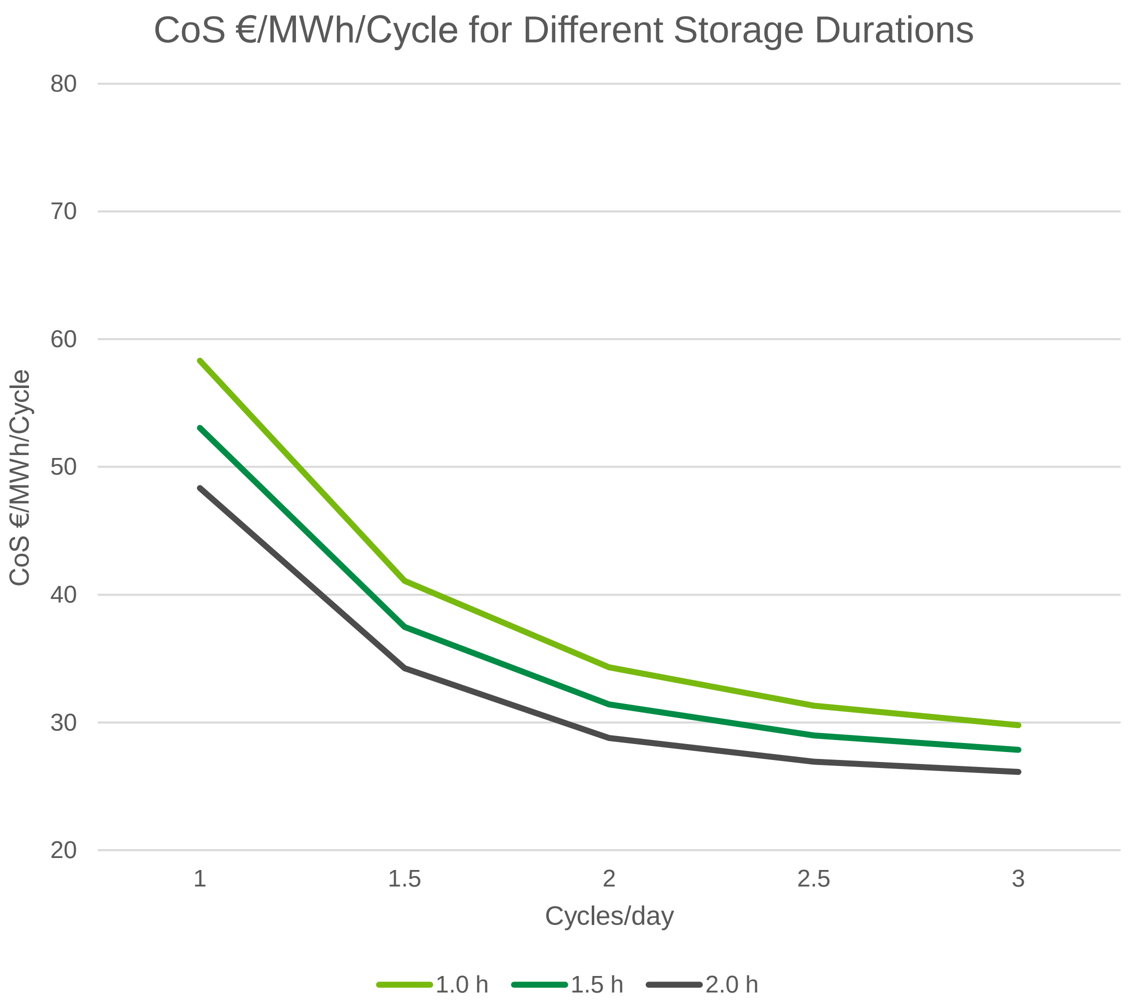
- *30 years project lifetime*

Sensitivity Analysis

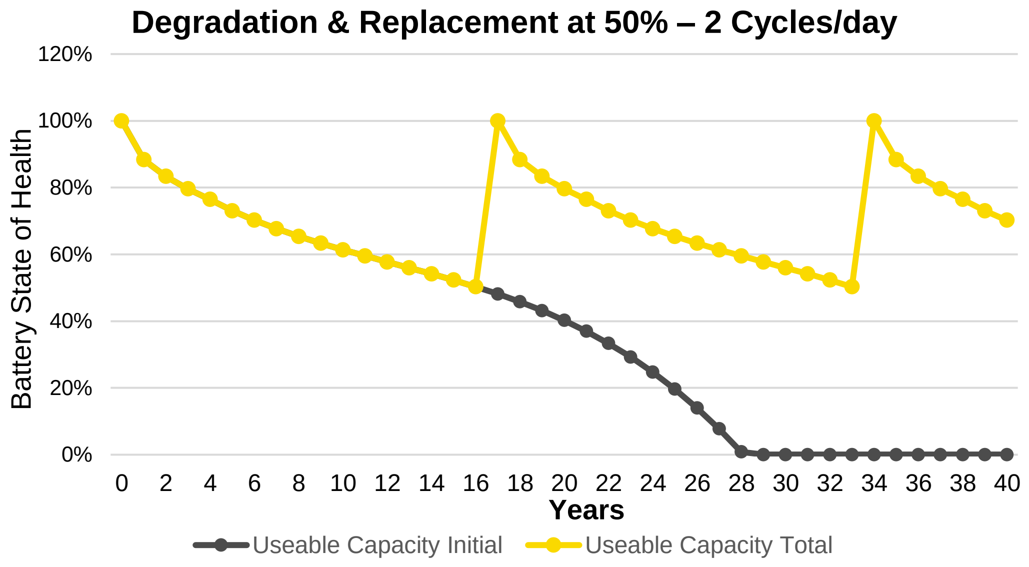
- With replacement at 70%, the prices go up again at 2.5 Cycles/day due to replacement happening at **early stages** in the project lifetime and **more frequent** replacement is required.



Cost of Storage – Replacement at 50% SOH

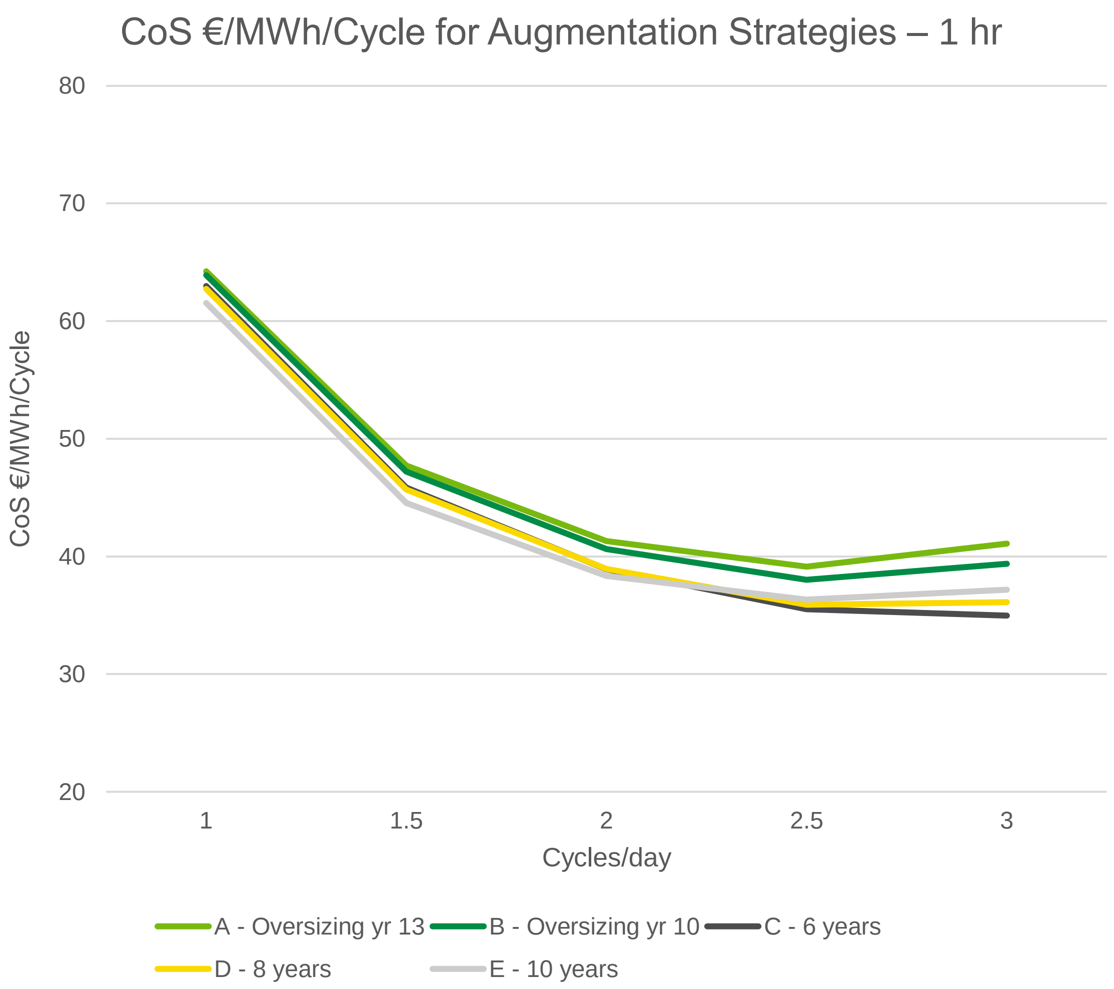


- **Sensitivity Analysis**
  - With replacement at 50%, prices continue going down despite the higher cycling as replacement happens at a **later stage** and **less frequent** replacement is required.



- *30 years project lifetime*

Cost of Storage – Augmentation



- Augmentation Strategy A: Oversizing for 100% in year 13, then 3 steps successive augmentations
- Augmentation Strategy B: Oversizing for 100% in year 10, then 3 steps successive augmentations
- Augmentation Strategy C: Every 6 years
- Augmentation Strategy D: Every 8 years
- Augmentation Strategy E: Every 10 years

- *30 years project lifetime*

Replacement VS Augmentation

	Replacement	Augementation
CAPEX	Clear upfront higher than augmentation	Clear upfront lower than replacement
OPEX	Constant over project lifetime	Increasing over project lifetime
Useable energy during project lifetime	Varies	Consistent
CoS 2 cycles 1h	~50 €/MWh (30yr)	~40€/MWh (30yr)
Suitability	Dependent on project requirements, a **hybrid scenario** of both strategies could be explored	

Conclusion

- Revenue of storage needs to justify the **cost of storage**.
- **Point of battery connection** and **system integration** level define the installed system capacity.
- Capacity maintenance strategies should be decided based on **specific project parameters** and **future project outlook**; e.g. available area, required average useable battery capacity, operation and cycling, second life of battery, project financing.
- The techno-economic **optimal number** of cycles is from **1.5 – 2.5 cycles per day**. The question of how many cycles to operate the battery on depends on the **application** and the **market in which the battery operates**.
- For battery storage system installations, each application, market, and operation methods should be **analyzed individually** and **in detail** in order to find the best **techno-economic solution**.

Thank you!

Any Questions?

Dina Jaber – Martin Dennenmoser
R&D Engineering Battery Storage
dina.jaber@baywa-re.com
martin.Dennenmoser@baywa-re.com

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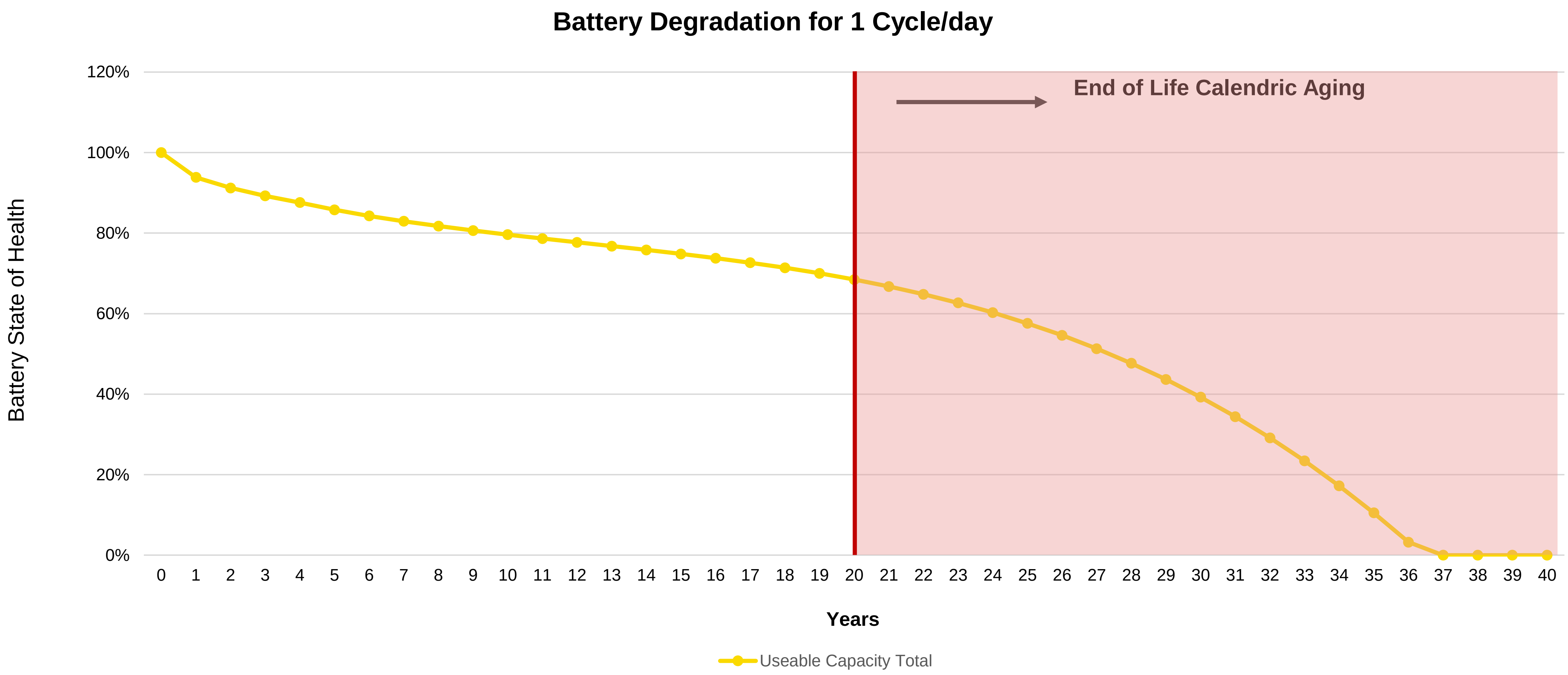
Battery Degradation & End of Life



Augmentation Strategies

- Augmentation Strategy A: Oversizing for 100% in year 13, then 3 steps successive augmentations
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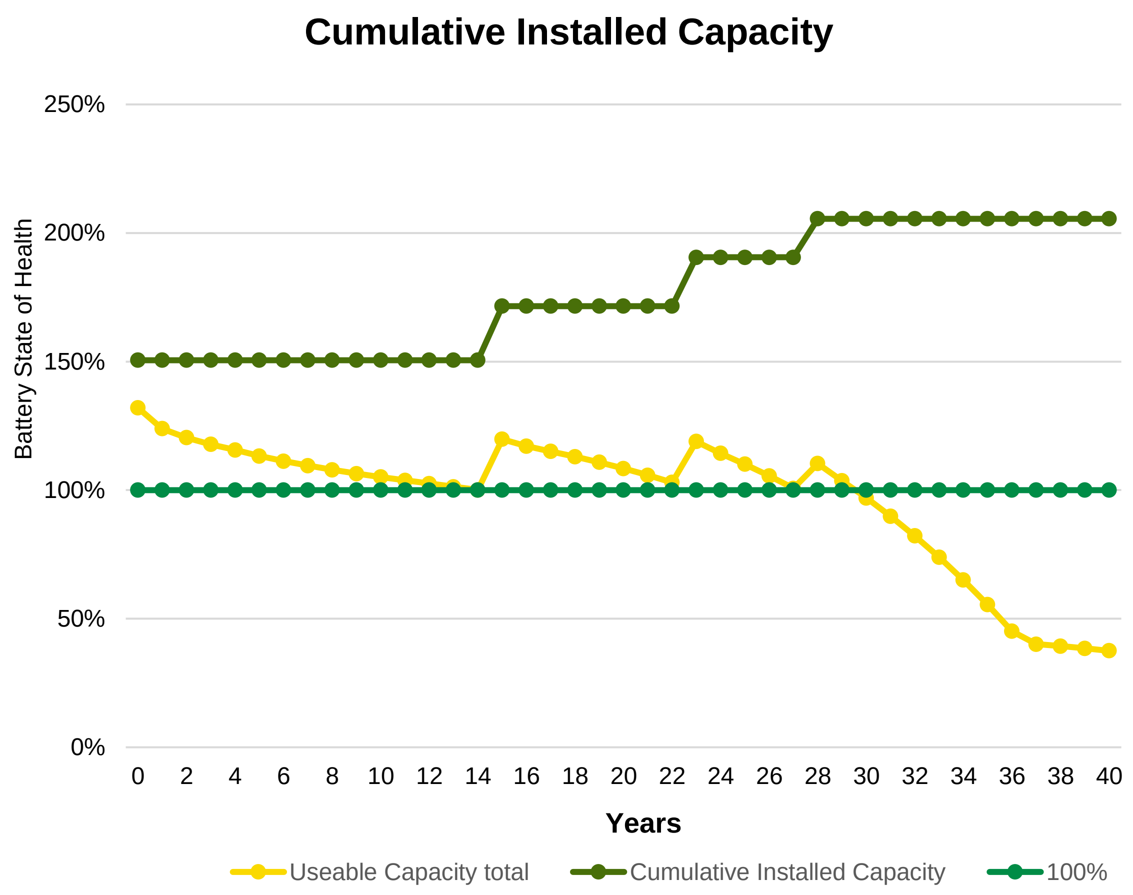
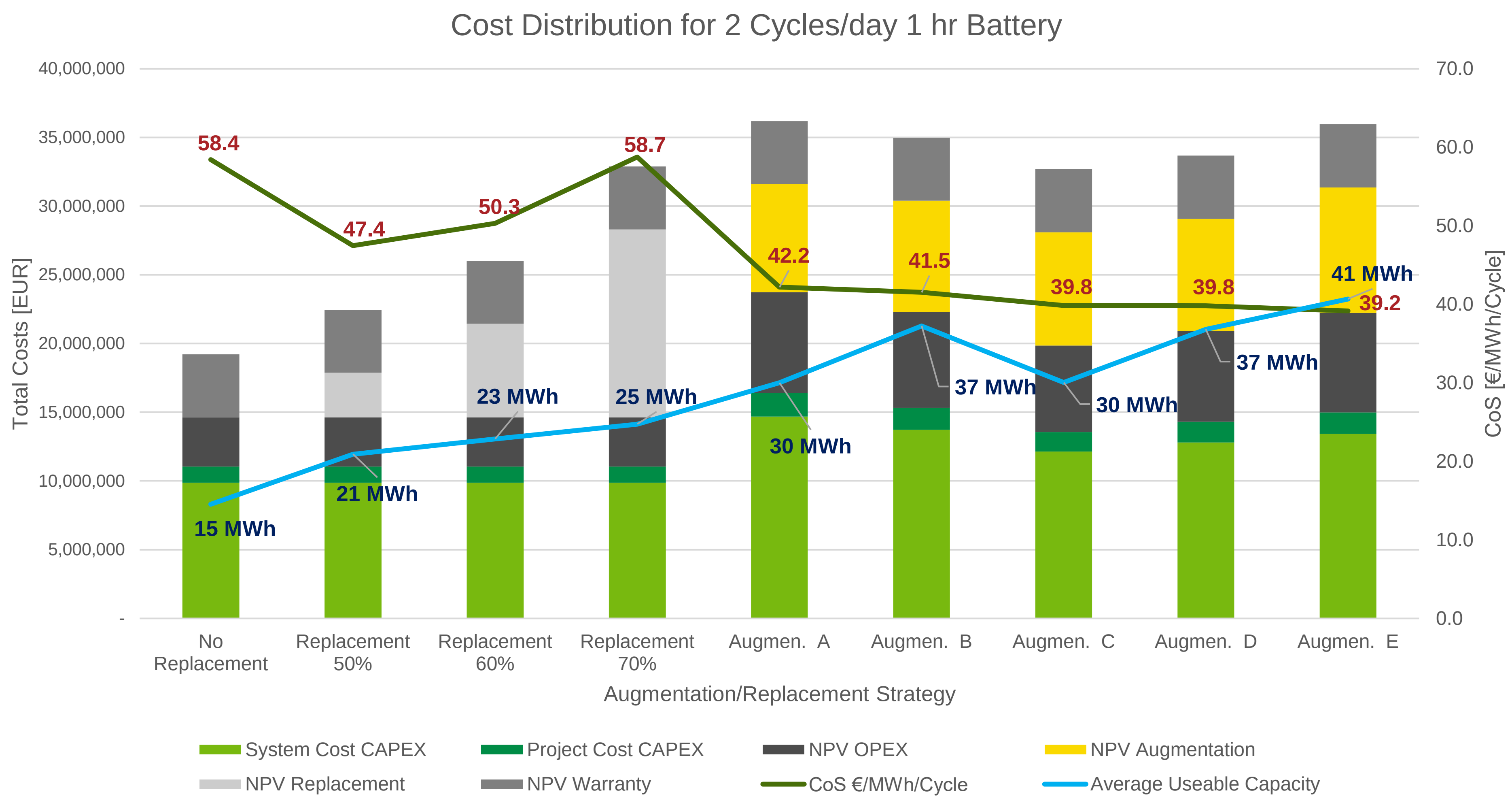


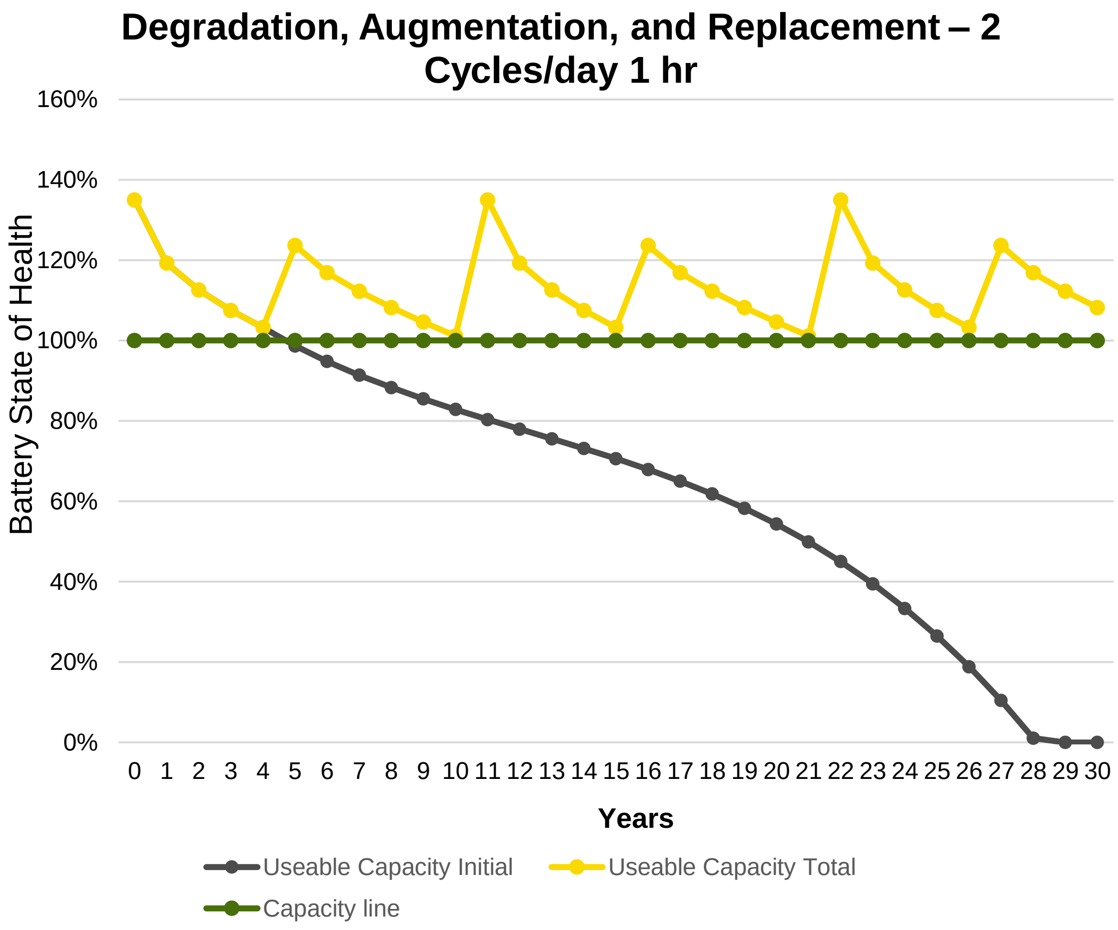
Cost Distrubution – 2 Cycles/day 1 hr Battery



- **Higher average useable capacity leads to lower cost of storage despite high project costs, but only up to a certain point.**

- *30 years project lifetime*

Replacement and Augmentation – Hybrid Scenario

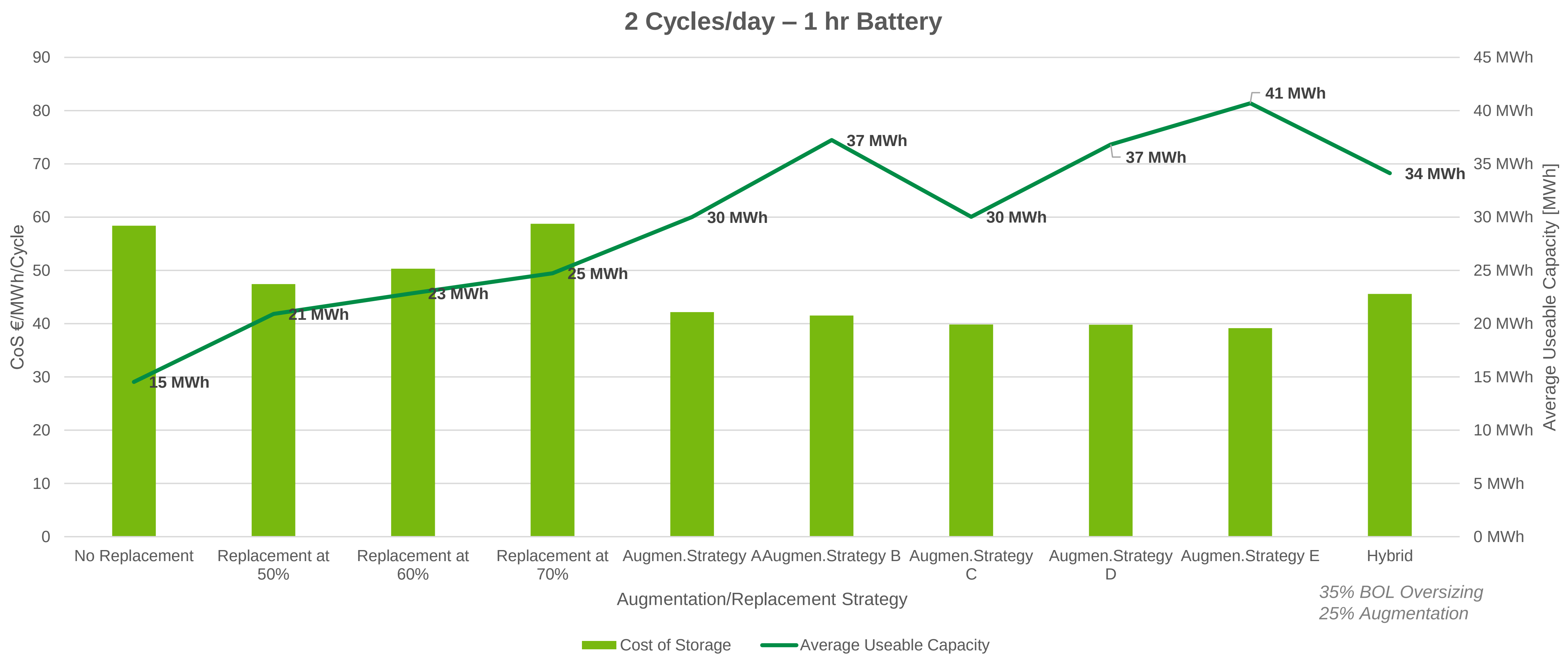


A hybrid strategy of Augmentation and Replacement was analysed as a possible techno-economical compromise between the two strategies.

Strategy: 35% Beginning of Life (BOL) oversizing, and a one time 25% augmentation before the next replacement.

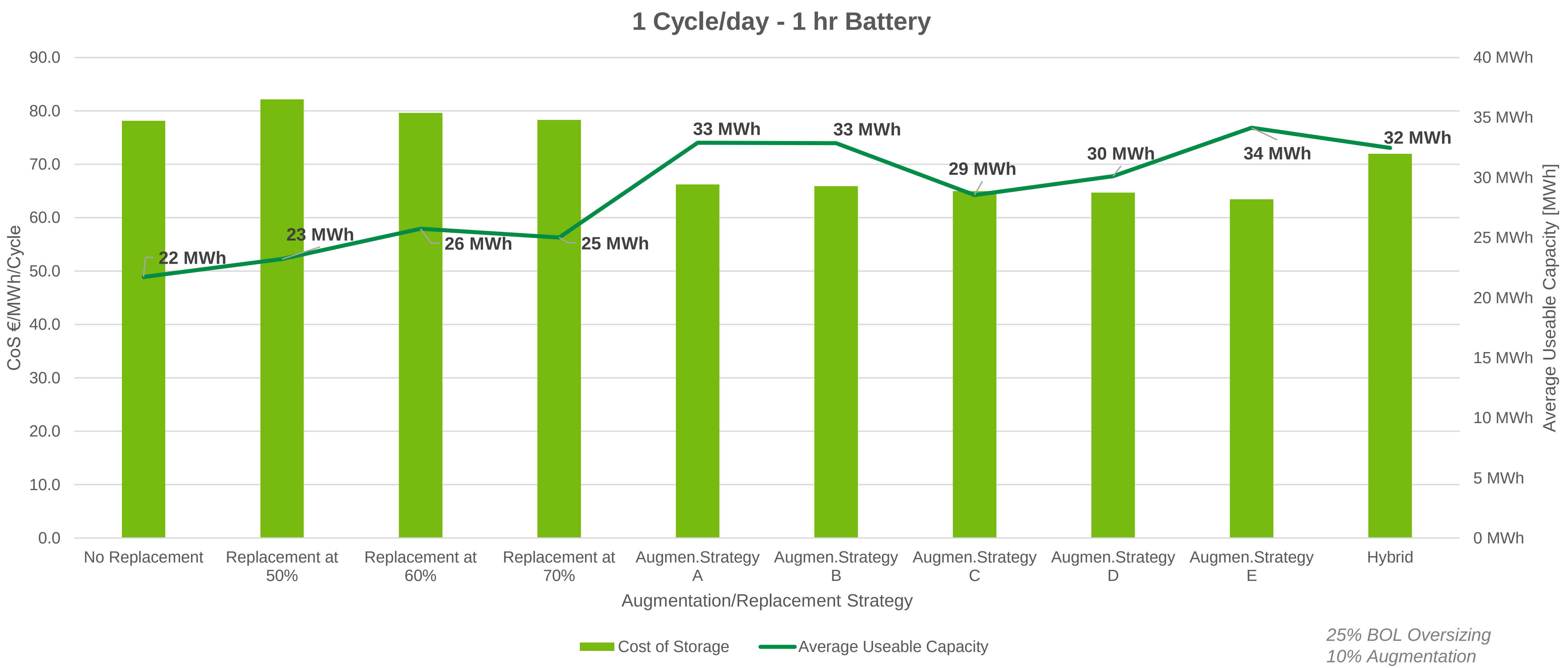
- *30 years project lifetime*

Comparison – Replacement VS Augmentation VS Hybrid



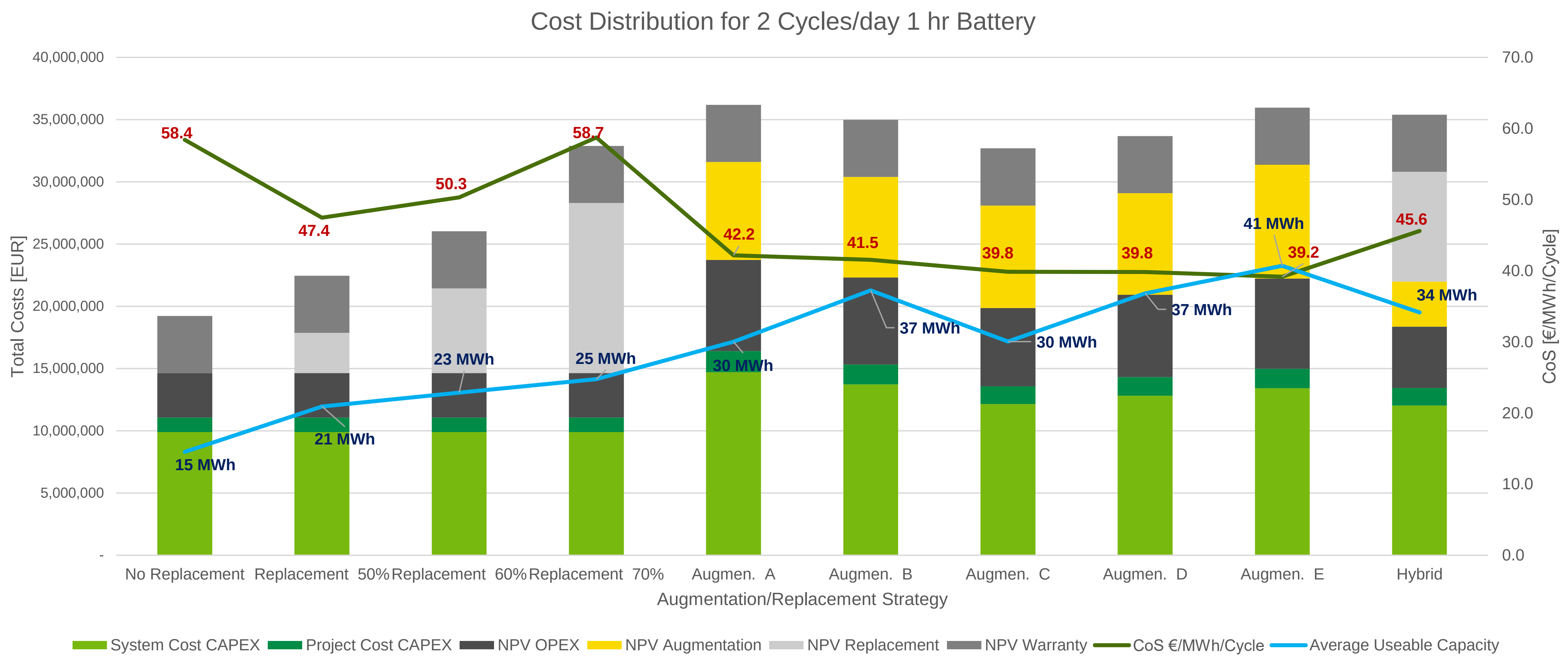
➢ *30 years project lifetime*

Comparison – Replacement VS Augmentation VS Hybrid



25% BOL Oversizing
10% Augmentation

Cost Distrubution incl Hybrid – 2 Cycles/day 1 hr Battery



- *30 years project lifetime*