AGING – AFFECTING SAFETY, RELIABILITY AND PERFORMANCE OF STATIONARY BATTERY STORAGE

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Fraunhofer Institute for Solar Energy Systems ISE

International Battery Seminar

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www.ise.fraunhofer.de

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AGENDA

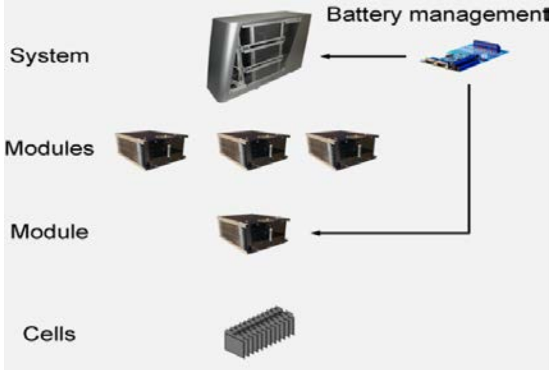
- Introduction to battery research, development and services at Fraunhofer ISE
- Considered market segments of stationary battery storage
  - Residential PV battery systems
  - District storage systems
- Key factors for storage product and project evaluation
  - Test results of market available residential PV storage systems
  - Extensive study of a district battery storage
- Conclusions

Department Electrical Energy Storage
Overview – Research, Development and Services

Battery Cell Technology
materials, architecture, production

- Development and characterization of materials and battery cells
- Development of process technologies
- Aqueous systems for stationary energy storage
- Lithium ion battery cells
- Solid state battery cells
- Technical and economical analysis
- Life cycle analysis

Battery Engineering
from cells to systems



- Cell formation
- Cell and system characterization
- Ageing and performance scrutiny
- System design and engineering
- Thermal management
- Battery management
- Algorithms for state estimation and life time prediction
- Optimized charging and operating control strategies

Applied Storage Systems
system design, integration and quality assurance

- Realization of lighthouse projects
- Business case development
- Consulting during complete life cycle of storage projects
- System modelling, analysis and optimized system design
- Simulation based storage sizing
- Energy management systems
- Technical due diligence: Site inspection, testing and monitoring

TestLab Batteries
electrical, thermal, mechanical testing

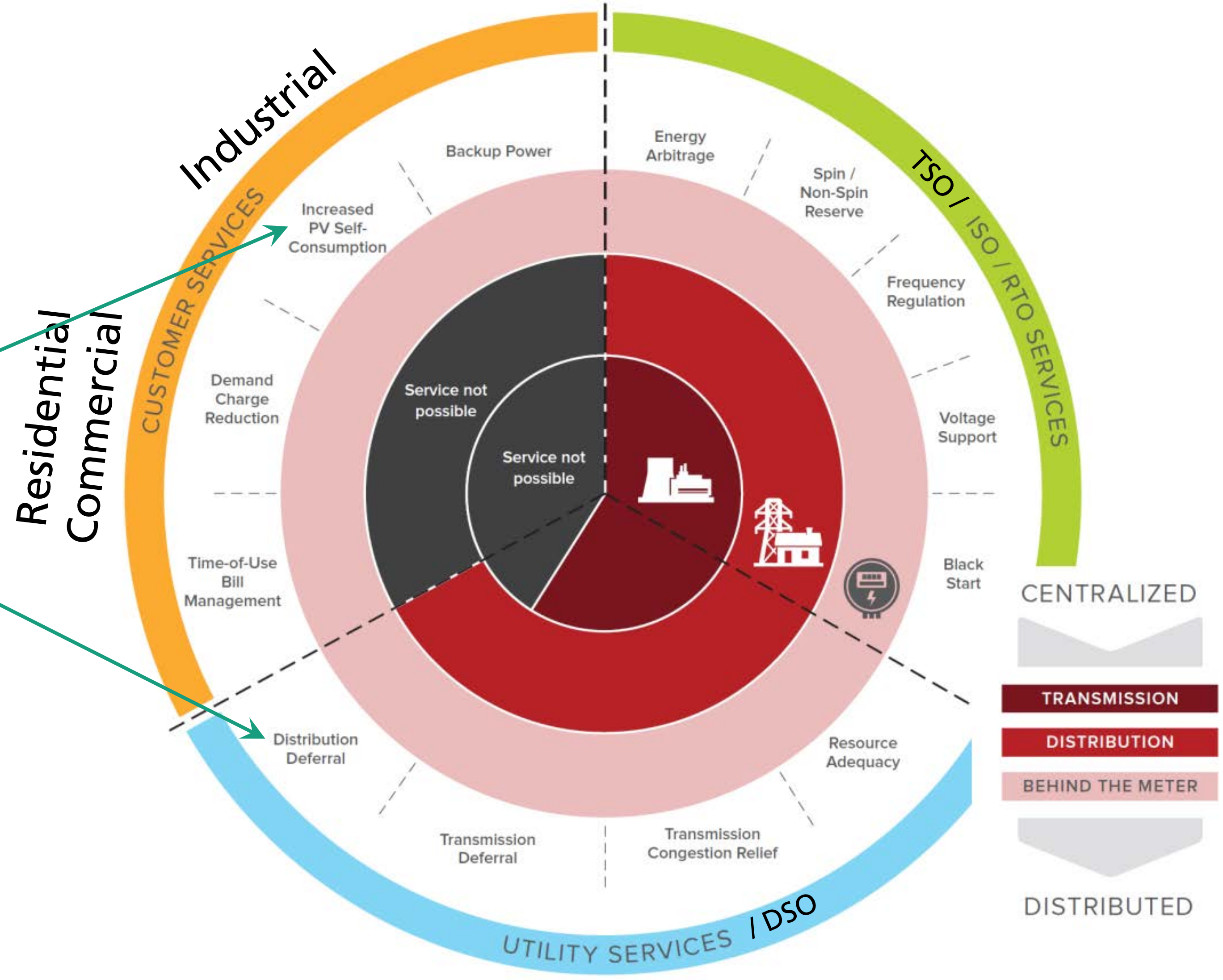
- Ageing: calendric and cyclic
- Safety: components and systems including functional safety
- Reliability: consideration of operating conditions and system behavior with aged components
- Performance: efficiency and effectiveness
- End-of-line quality control for cell production

Market segments of stationary battery storage

Batteries can provide up to 13 services to three stakeholder groups

This presentation:

- Residential PV battery systems
- District battery storage



Source: F. Garrett, The Economics of Battery Energy Storage, Rocky Mountain Institute, September 2015.

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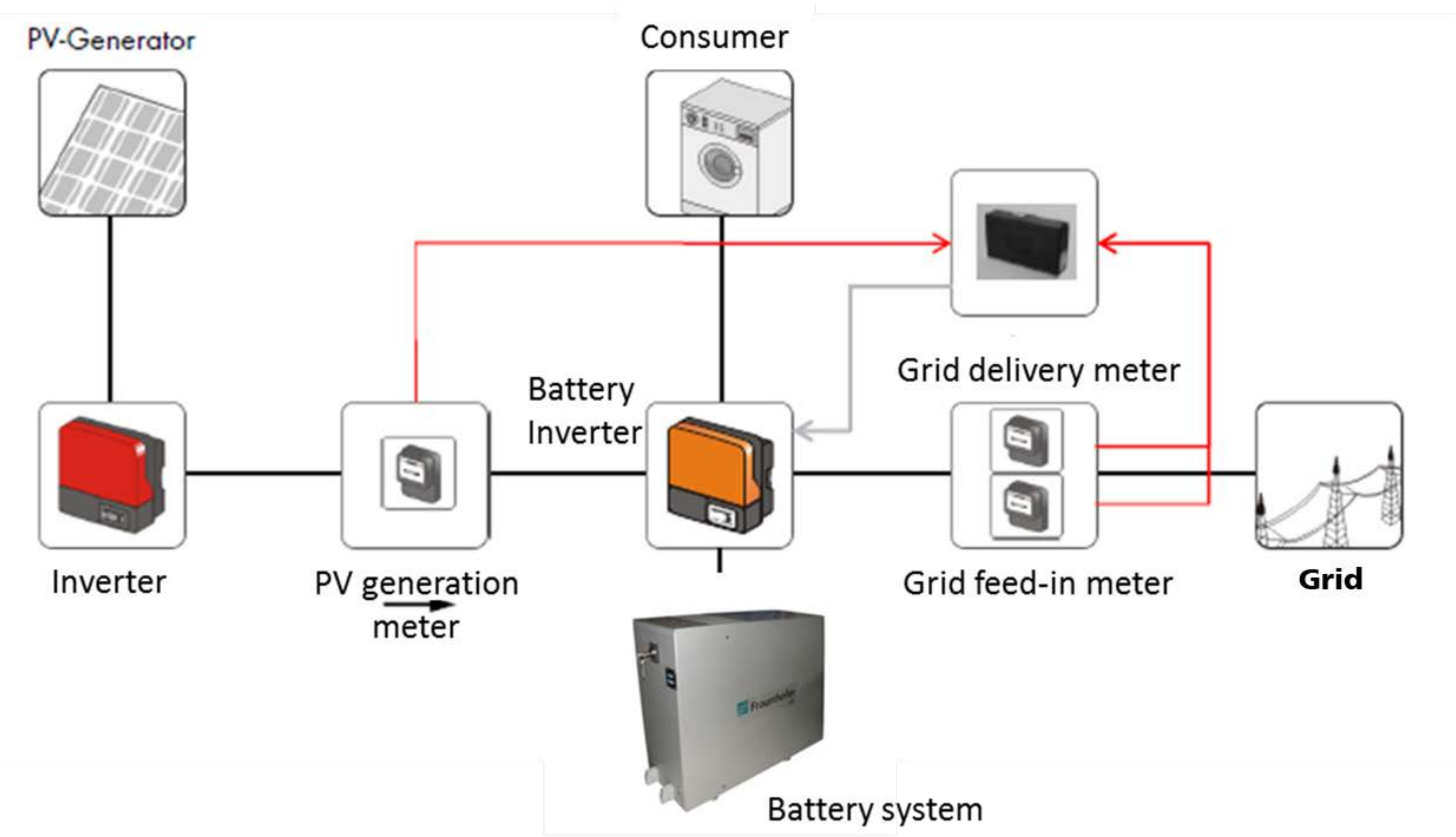
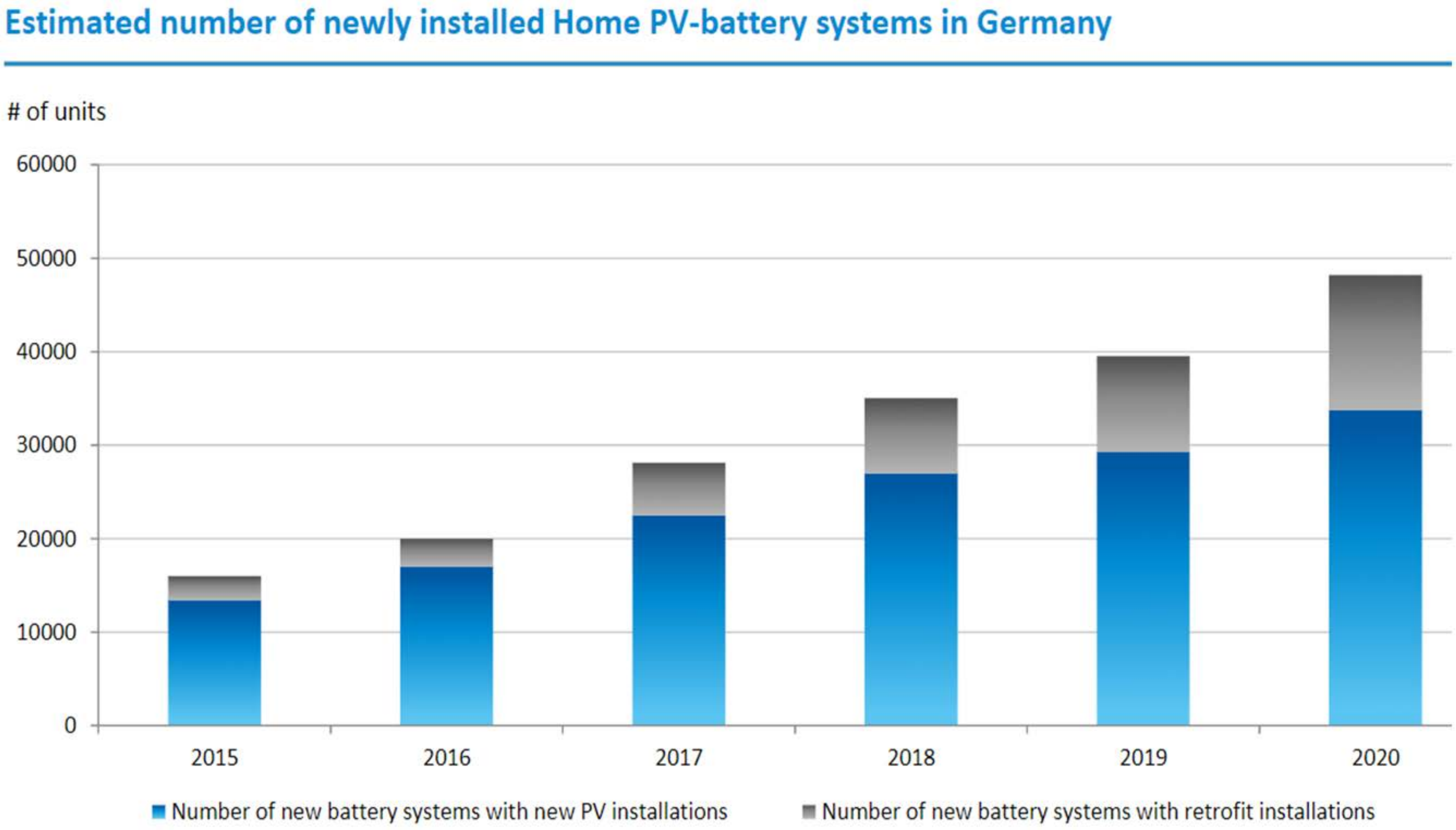
Market segments of stationary battery storage
Residential PV battery systems



Source: SMA

Market segments of stationary battery storage
Residential PV battery systems – Market development in Germany



Source: GTAI, 2019.

Market segments of stationary battery storage

District battery storage – Example: Solar settlement “Am Umstädter Bruch”

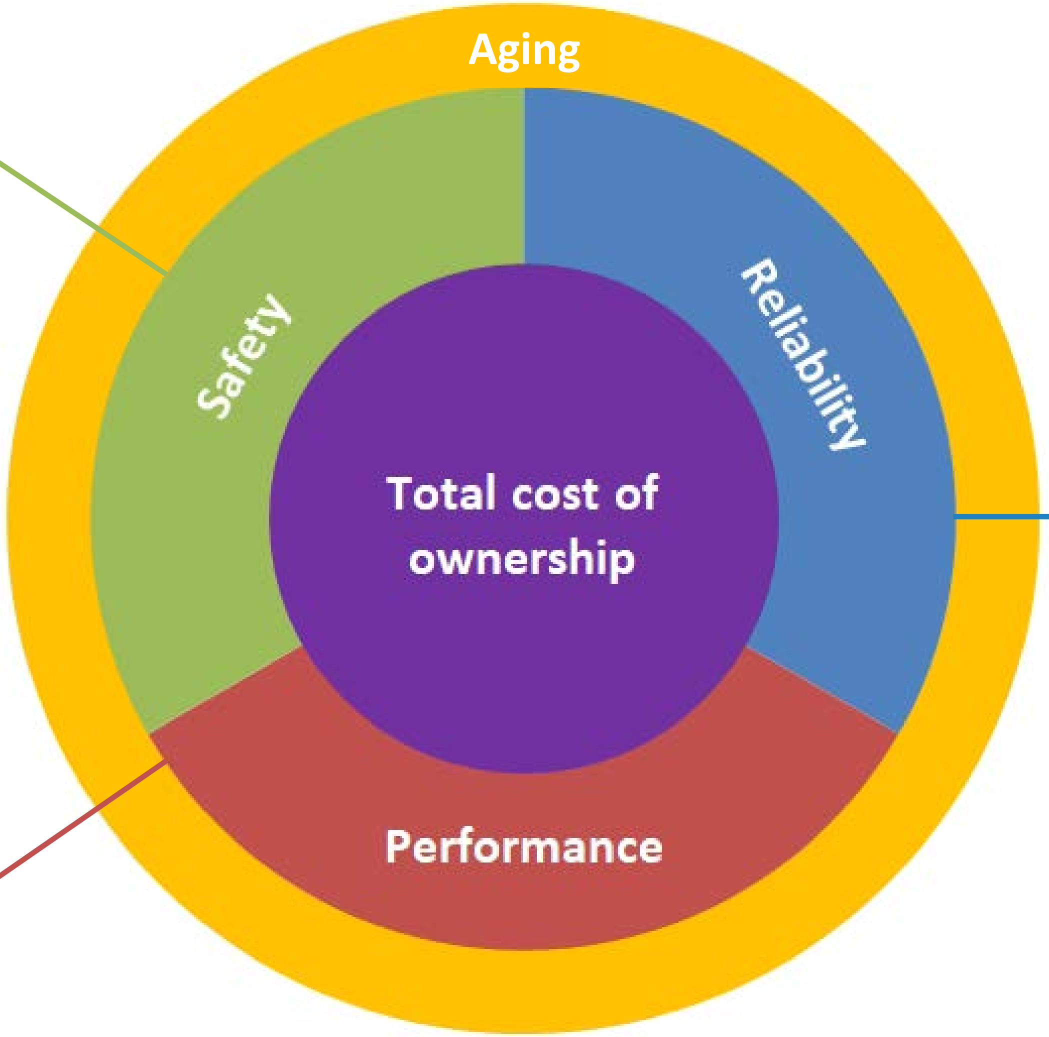
Battery storage:

250 kW / 800 kWh

StoREgio adstec entega h_da Hochschule Darmstadt University of Applied Sciences fbeit Fachbereich Elektrotechnik und Informationstechnik Fraunhofer IESE Fraunhofer ISE

Key factors for storage product and project evaluation

- Component and system level
- Functional safety



- Component and system level
- Operating conditions

- System efficiency
- System effectiveness

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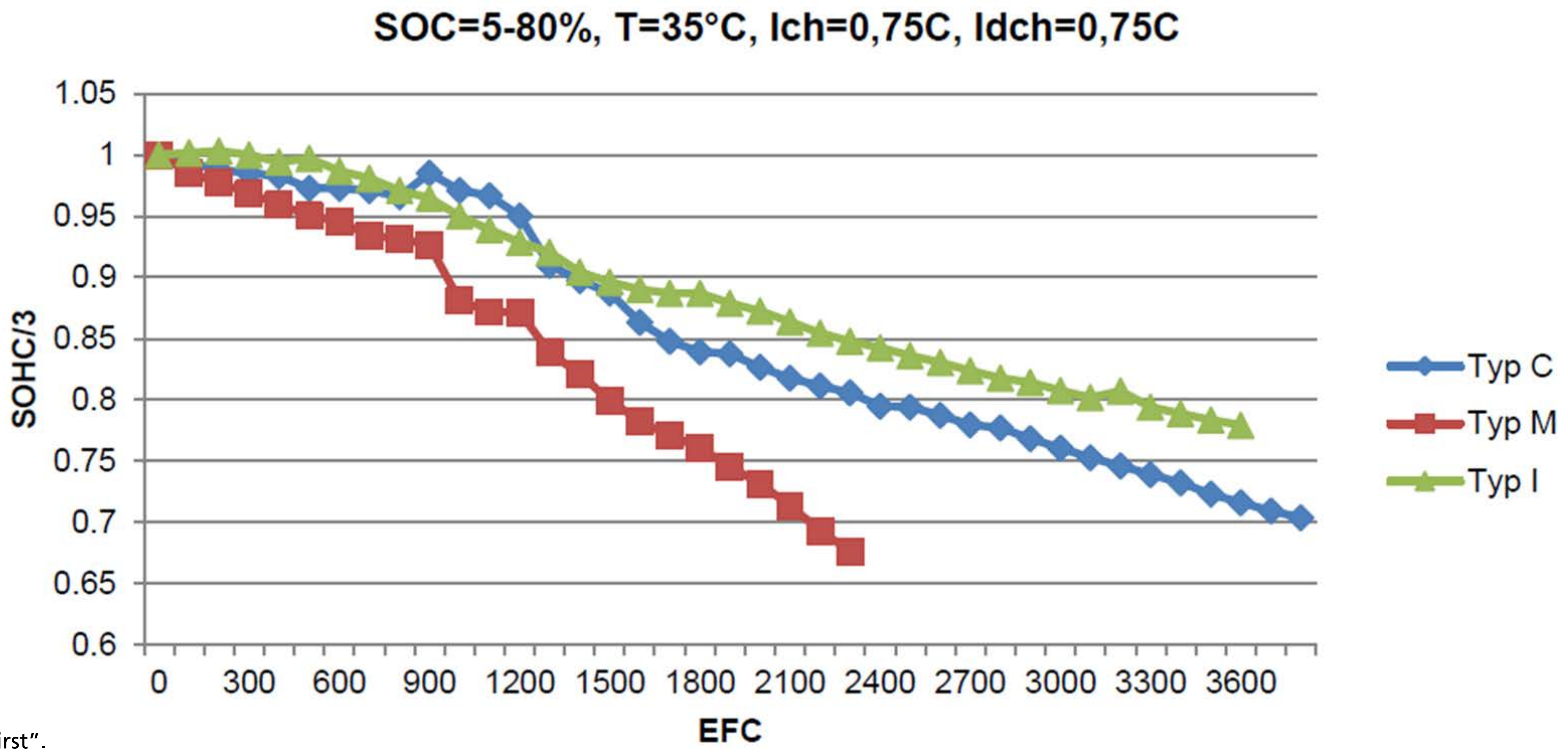
Aging of lithium-ion cells

Examples of market available products (residential PV storage systems)

Cyclic aging – Capacity fade



Source: Final report project “SafetyFirst”.

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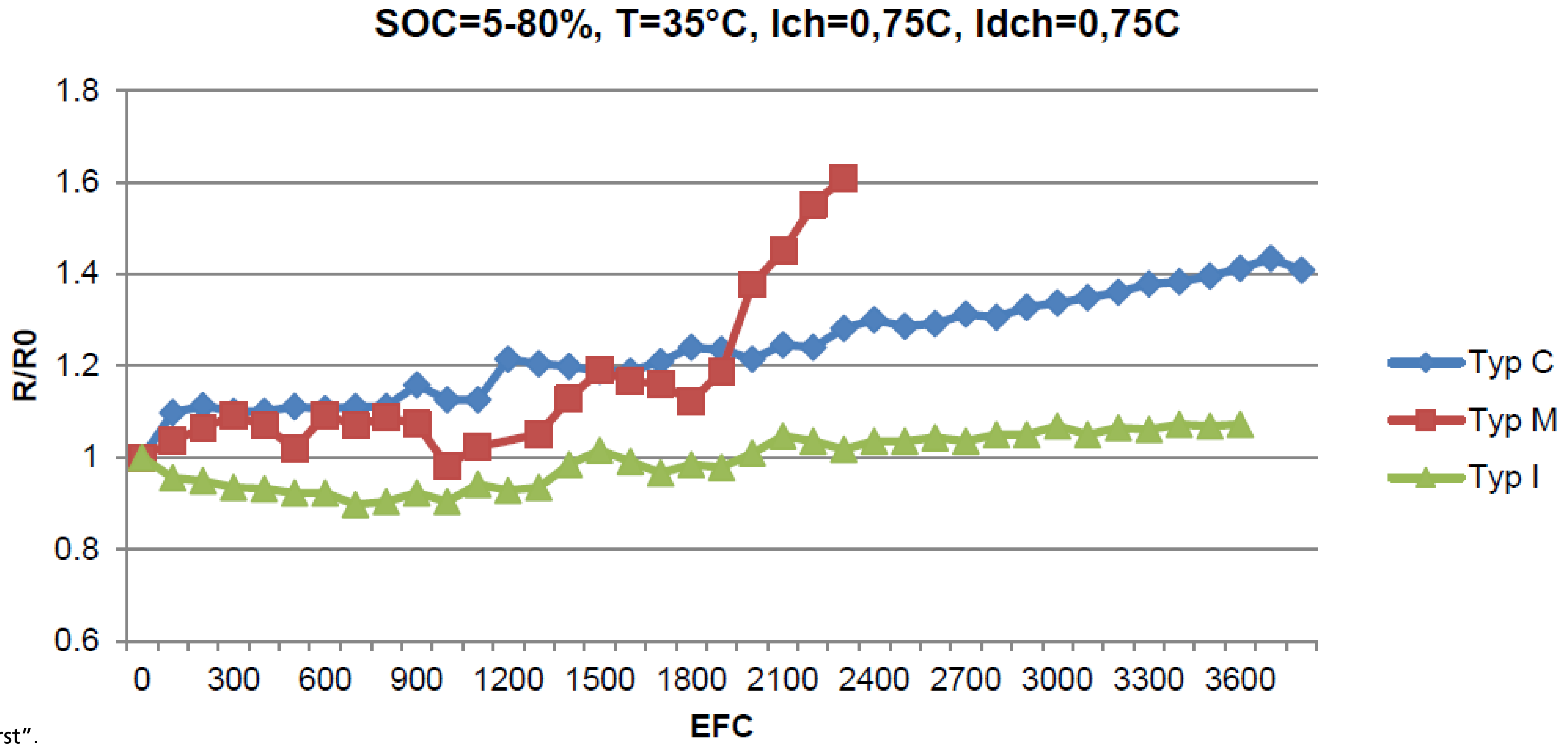
Aging of lithium-ion cells

Examples of market available products (residential PV storage systems)

Cyclic aging – Increase of inner resistance

Pulse test: 10 sec @ SOC = 50%

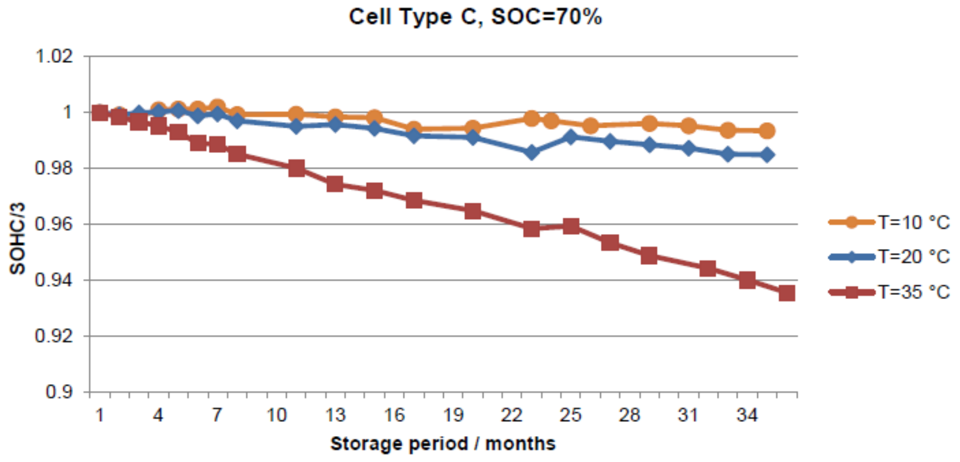


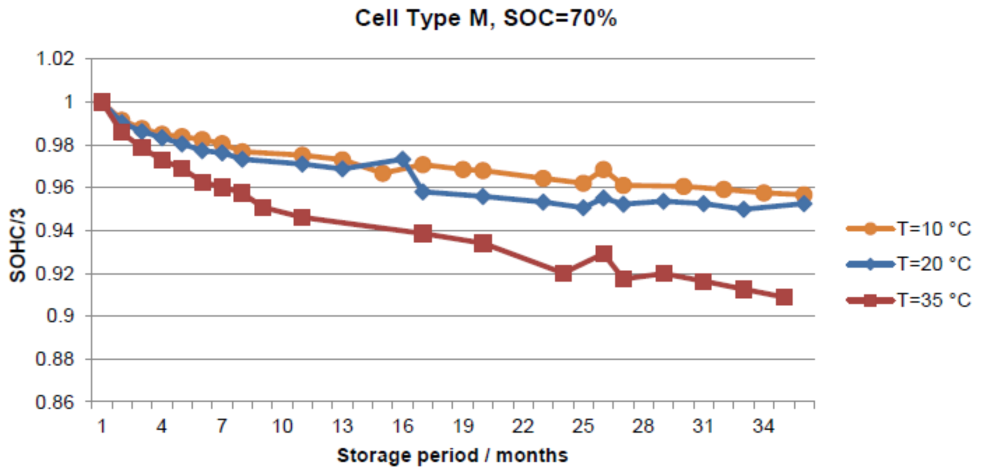
Source: Final report project "SafetyFirst".

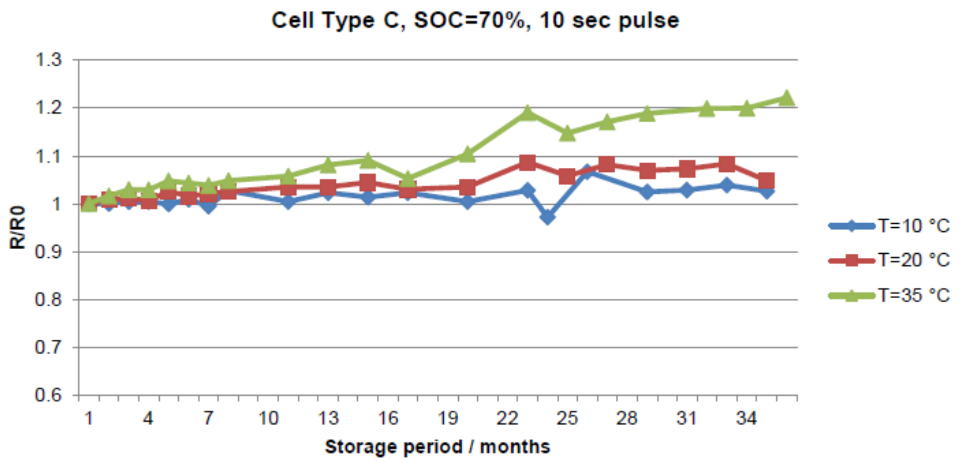
Aging of lithium-ion cells

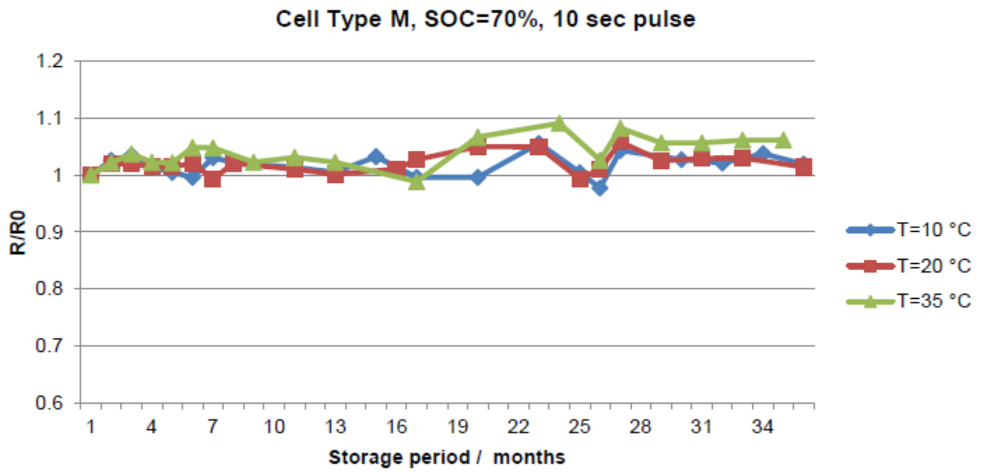
Examples of market available products (residential PV storage systems)

Calendric aging







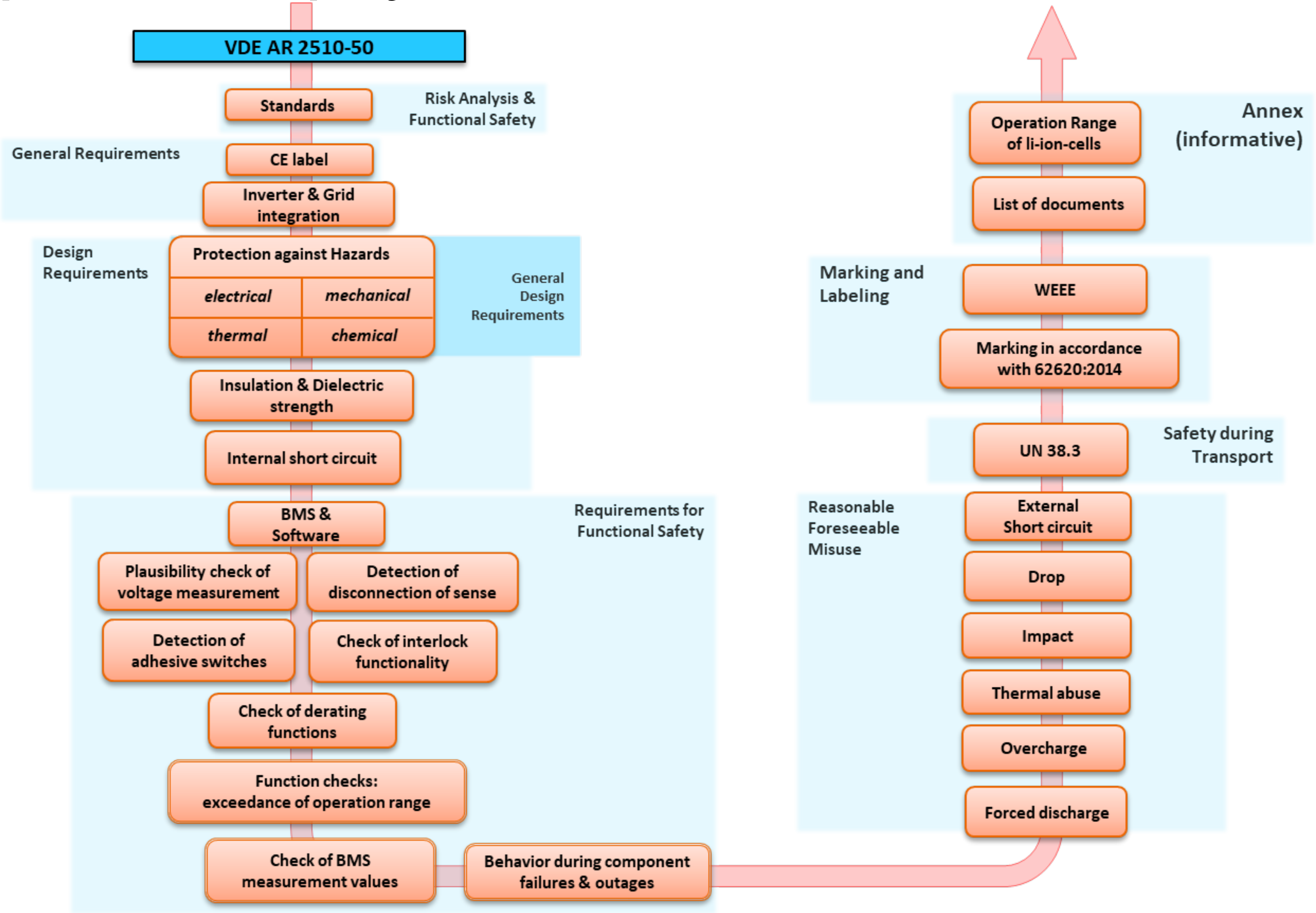


Source: Final report project "SafetyFirst".

Key factors for storage product and project evaluation
Safety

- Example VDE application rule VDE AR 2510-50:

  Stationary energy storage systems with lithium batteries – Safety requirements

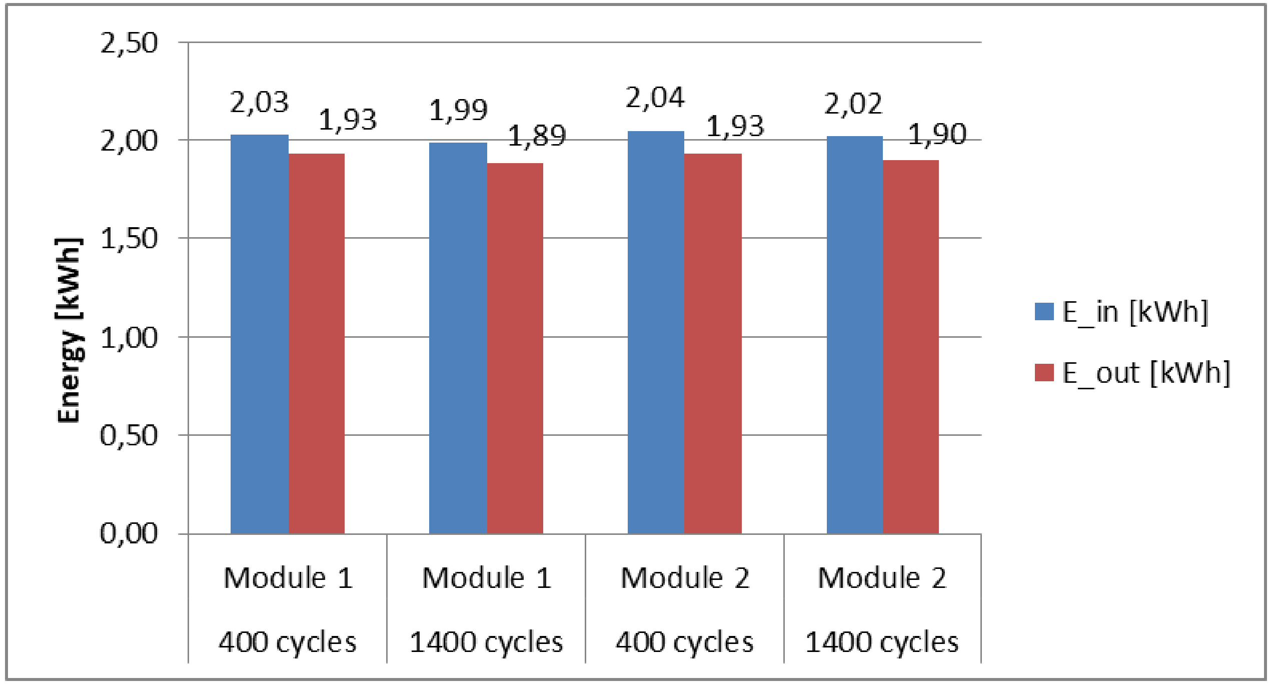


Key factors for storage product and project evaluation

Reliability – Example battery storage with aged battery modules

Battery storage product 1

- Little loss of capacity after 1400 cycles
- Loss of efficiency after 1400 cycles negligible
- Almost homogeneous aging behavior



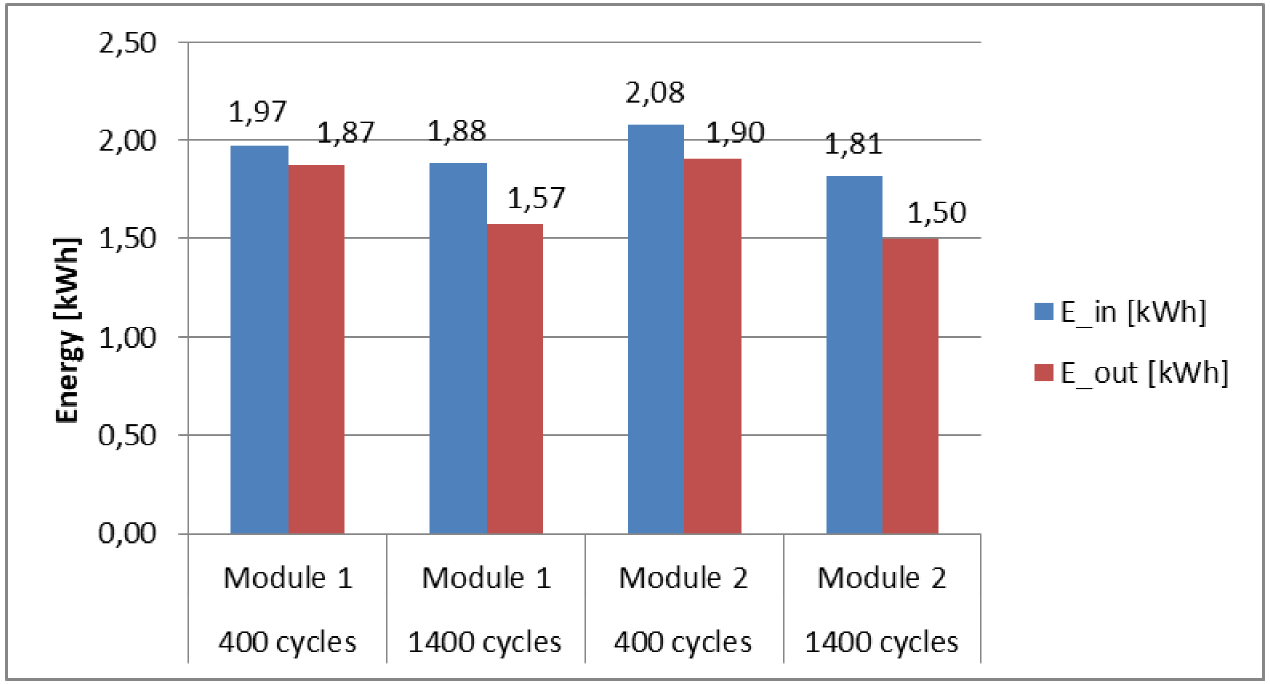
Number of cycles	**400**	**1400**	**400**	**1400**
	Module 1	Module 1	Module 2	Module 2
E_in [kWh]	2.03	1.99	2.04	2.02
E_out [kWh]	1.93	1.89	1.93	1.90
Efficiency	95.30%	94.91%	94.57%	94.04%
Capacity loss		2.44%		1.85%
Efficiency		0.39%		0.53%

Source: Final report project “SafetyFirst”.

Key factors for storage product and project evaluation
Reliability – Example battery storage with aged battery modules

Battery storage product 2

- Huge loss of capacity after 1400 cycles
- Huge loss of efficiency after 1400 cycles
- Inhomogeneous aging behavior



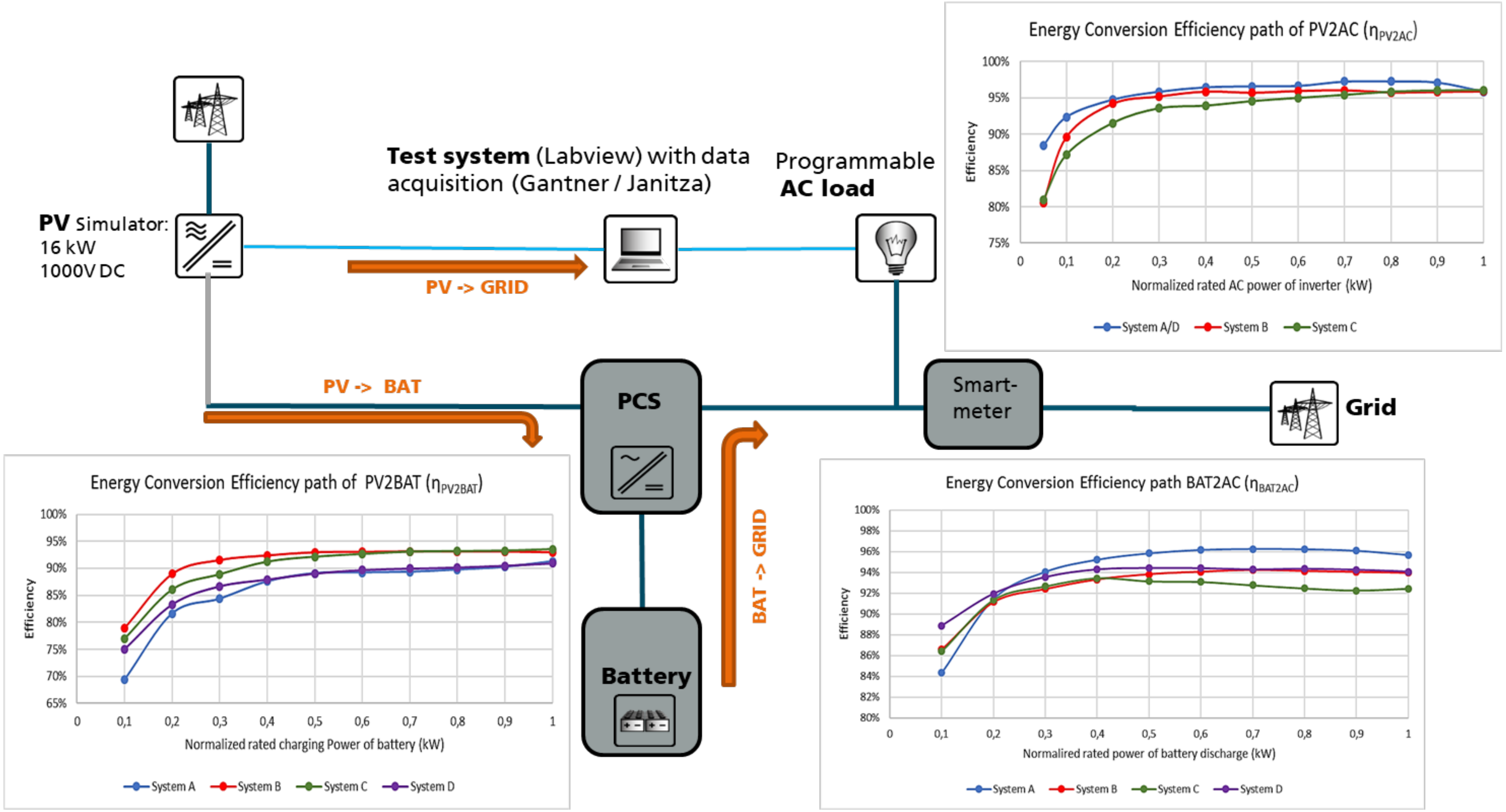
Number of cycles	400	1400	400	1400
	Module 1	Module 1	Module 2	Module 2
E_in [kWh]	1.97	1.88	2.08	1.81
E_out [kWh]	1.87	1.57	1.90	1.50
Efficiency	94.86%	83.71%	91.64%	82.63%
Capacity loss		15.99%		21.25%
Efficiency		11.15%		9.01%

→ Question of reliability:
Can the cooling system cope with the increasing heat generation of aged battery modules ???

Source: Final report project "SafetyFirst".

Key factors for storage product and project evaluation

Performance – Efficiencies: Examples of PV home storage systems



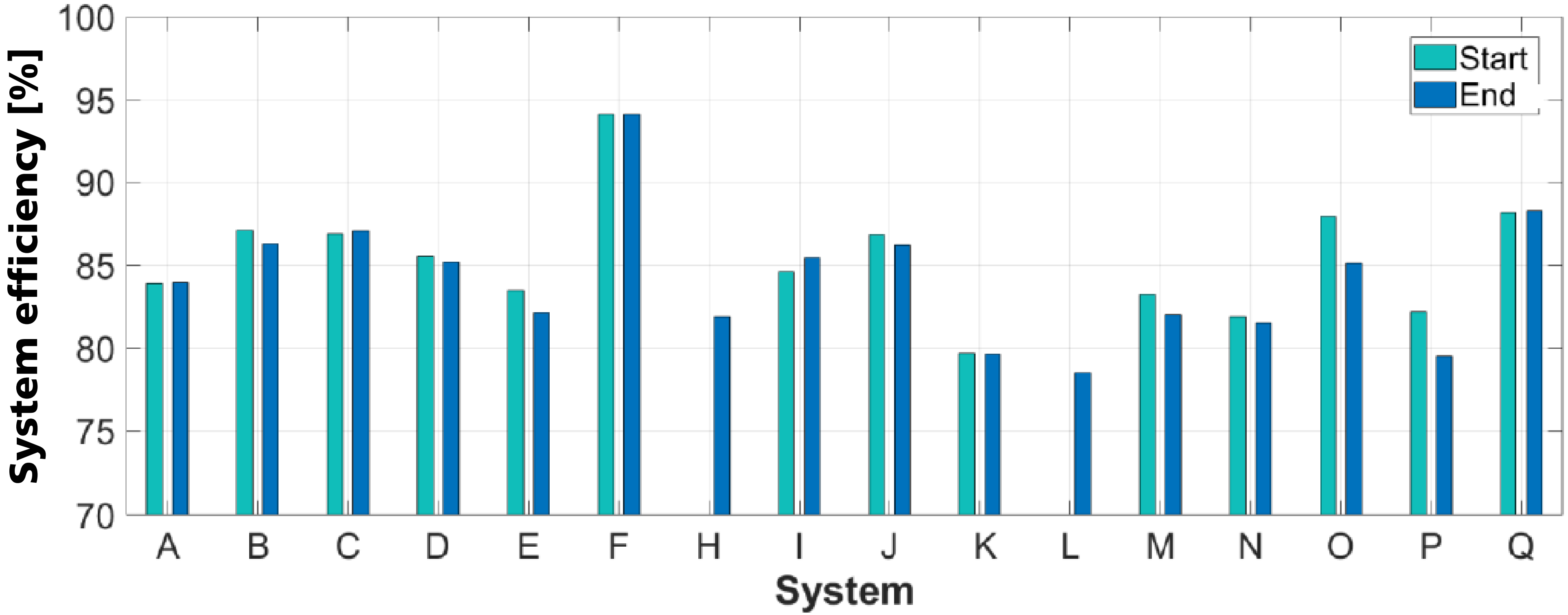
Source: Final report project “SafetyFirst”.

Key factors for storage product and project evaluation

Performance – Efficiencies: Examples of PV home storage systems

System efficiency tests at beginning and end of the project (after 3 years)

- PV system: 3.5 kWp
- Annual consumption: 4200 kWh



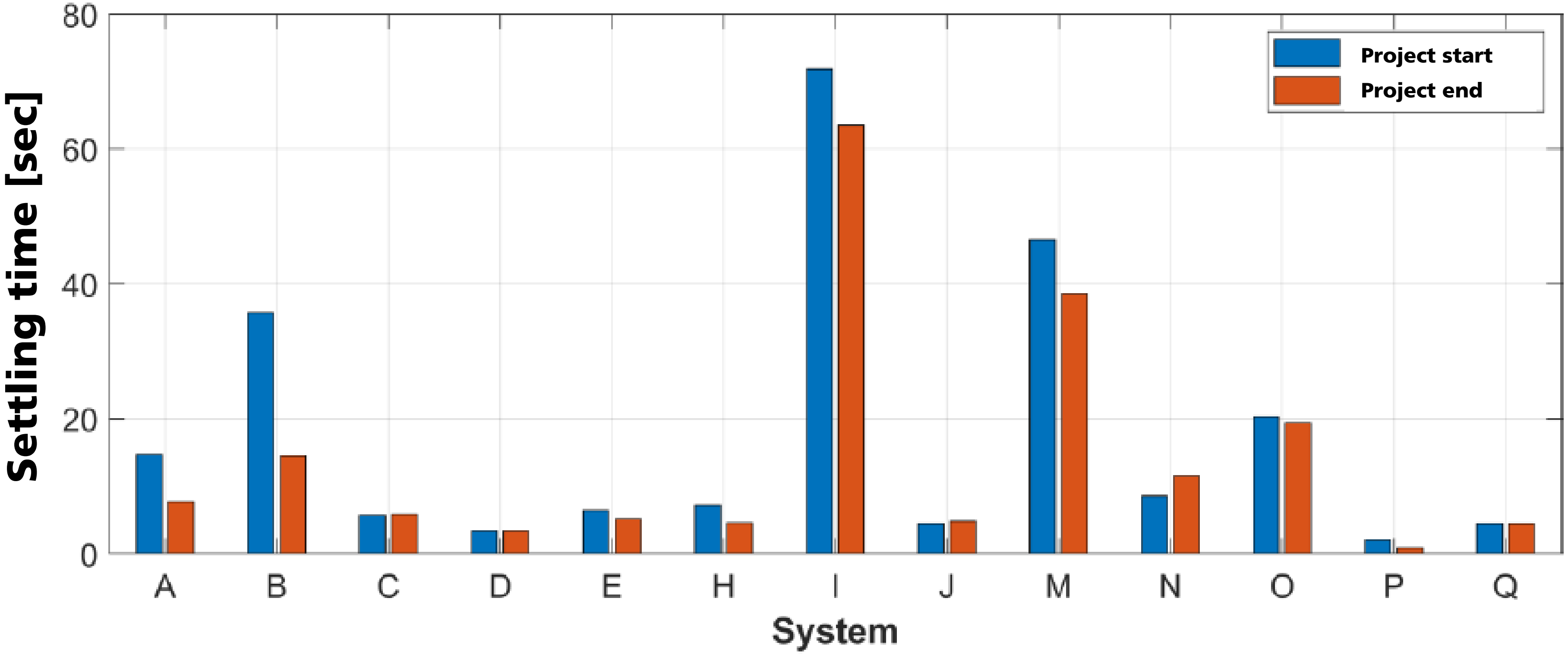
Source: Final report project “SafetyFirst”.

Key factors for storage product and project evaluation

Performance – Effectiveness: Examples of PV home storage systems

Settling time tests at beginning and end of the project (after 3 years)

→ Settling times have an impact on self-sufficiency rates



Source: Final report project "SafetyFirst".

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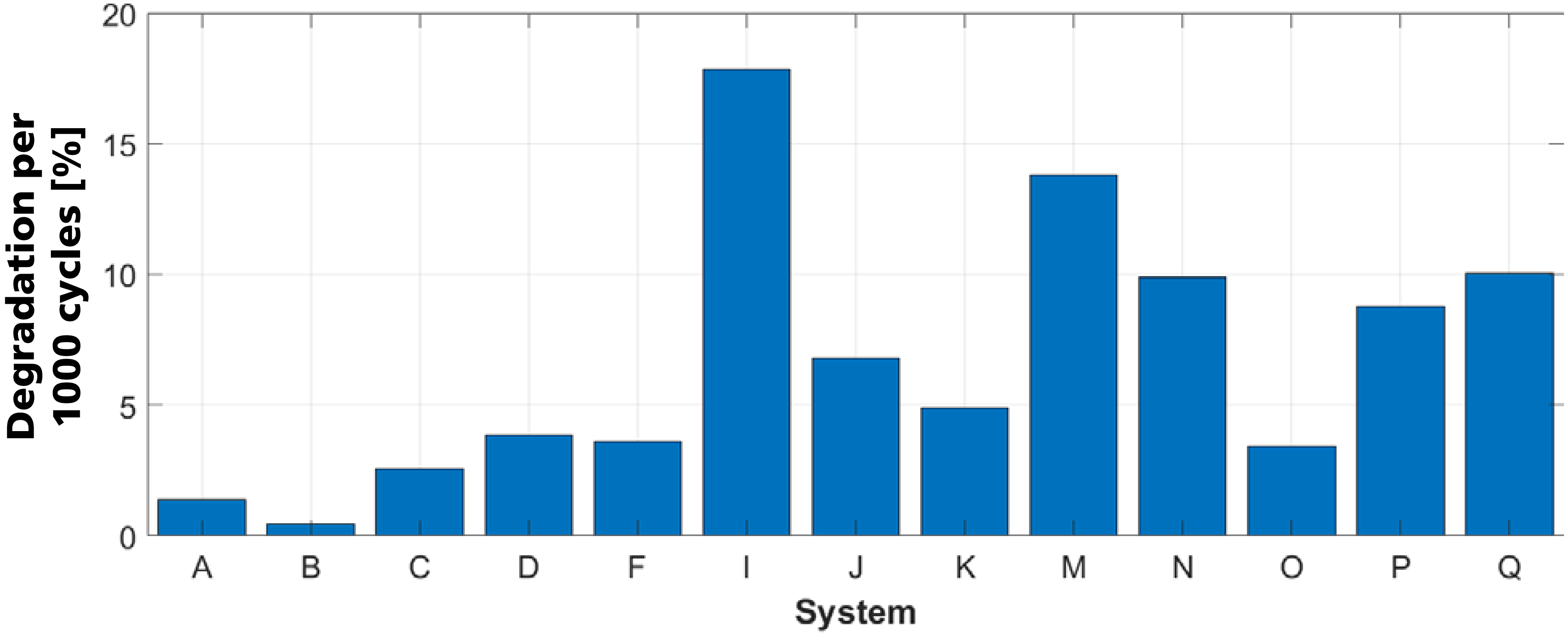
Key factors for storage product and project evaluation

Performance – Effectiveness: Examples of PV home storage systems

Degradation of battery capacities → Reduction of self-sufficiency over time



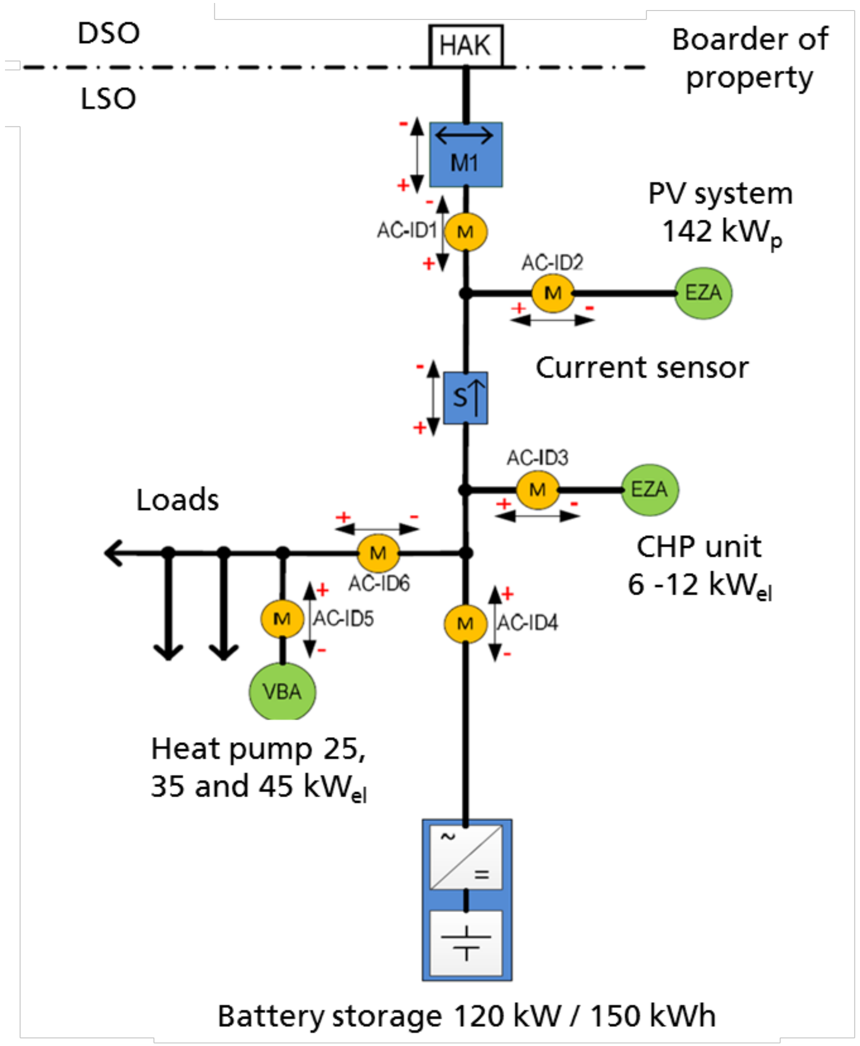
Source: Final report project “SafetyFirst”.

Key factors for storage product and project evaluation
Performance – Example of a district battery storage

Optimization criteria:

Minimization of grid dependency –

Physically not only accumulated

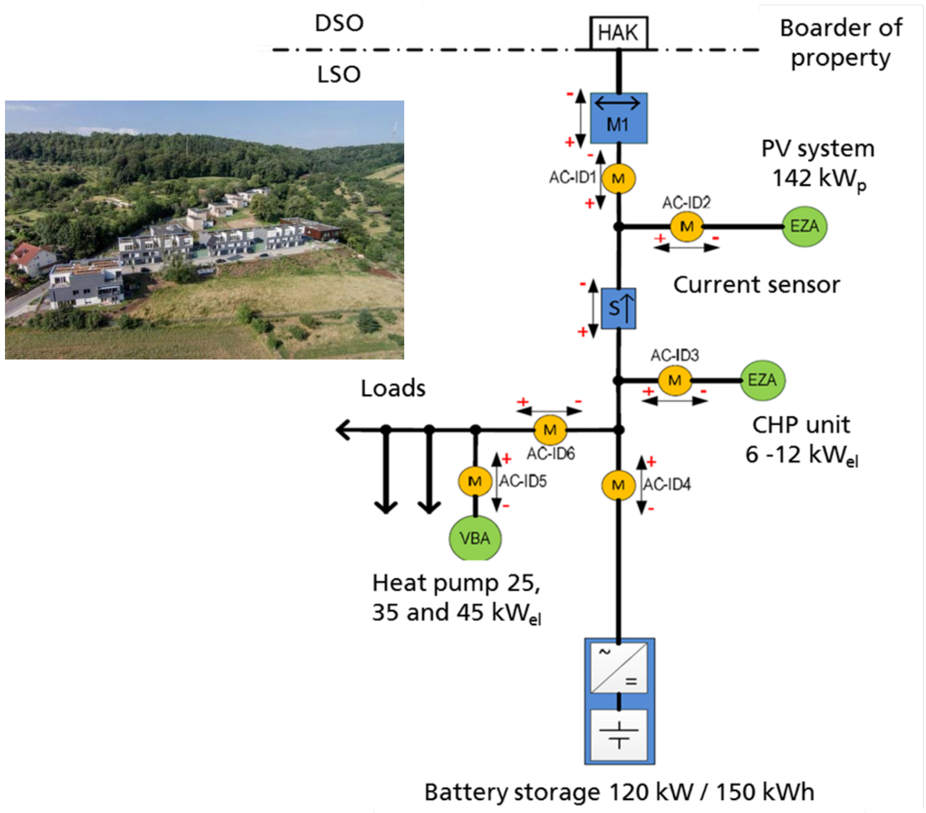


Key factors for storage product and project evaluation

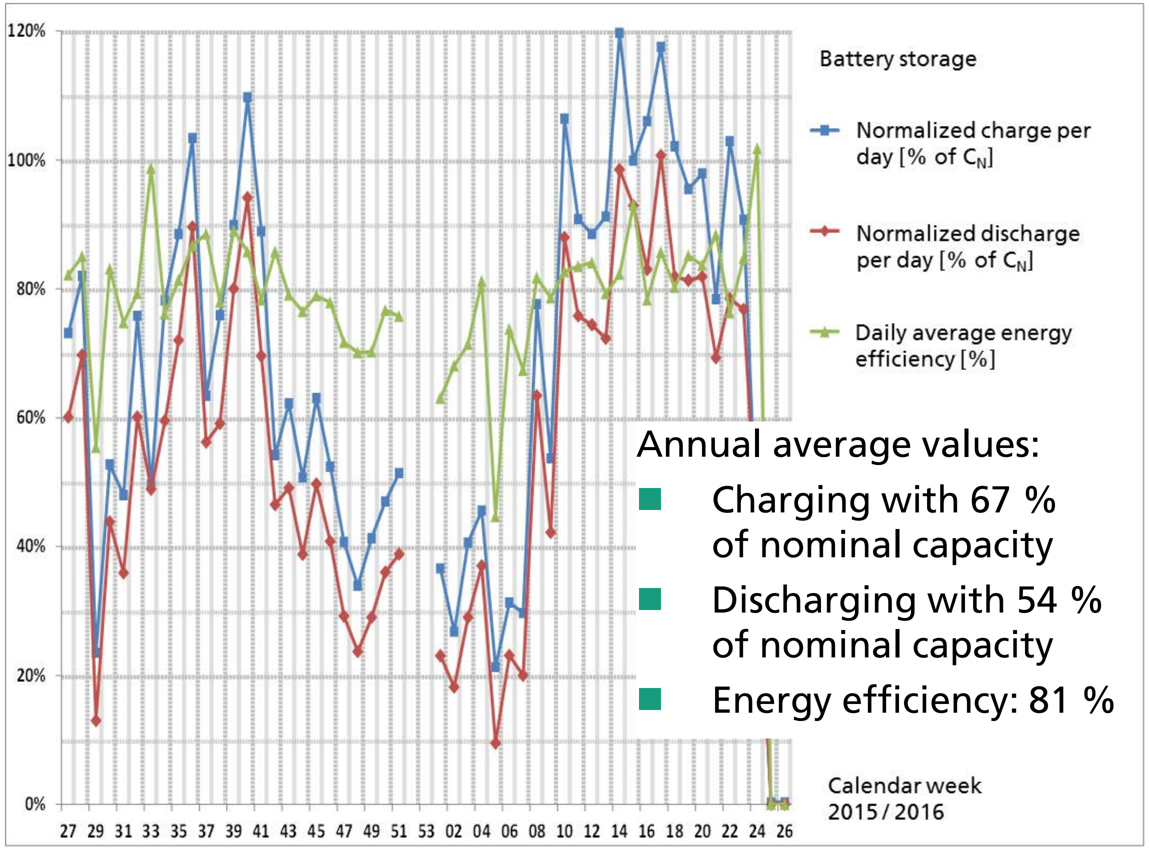
Performance – Efficiency: Example of a district battery storage

- Results of measurement campaign

System concept of district power supply



Analysis of battery storage operation



Annual average values:
- Charging with 67 % of nominal capacity
- Discharging with 54 % of nominal capacity
- Energy efficiency: 81 %

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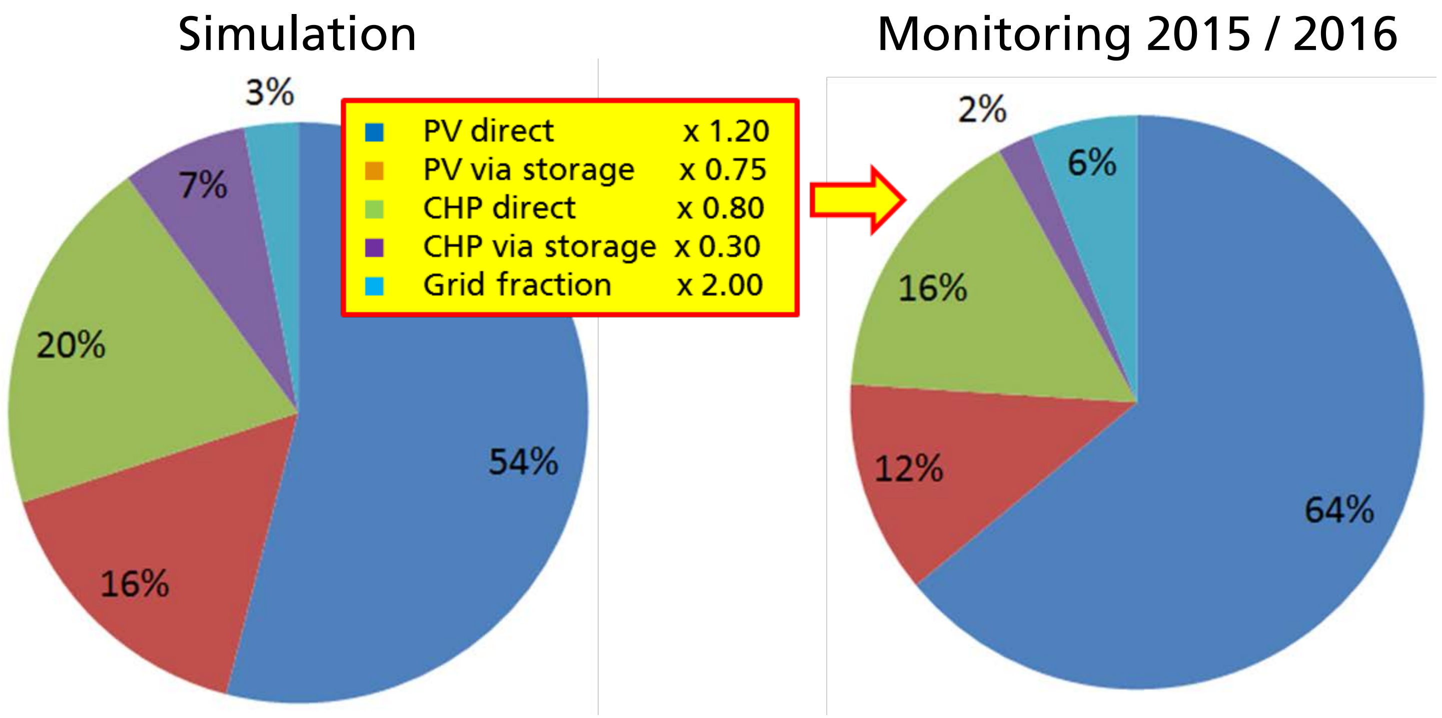
Key factors for storage product and project evaluation

Performance – Effectiveness: Example of a district battery storage

Accumulated annual electrical energy quantities



Reasons for differences:

- Problems with air conditioning → To high temperatures in operation room → Shut-down of CHP unit and battery inverter
- Necessary maintenance interval of CHP unit in winter (!)
- End-users do not behave 100 % as predicted (!)

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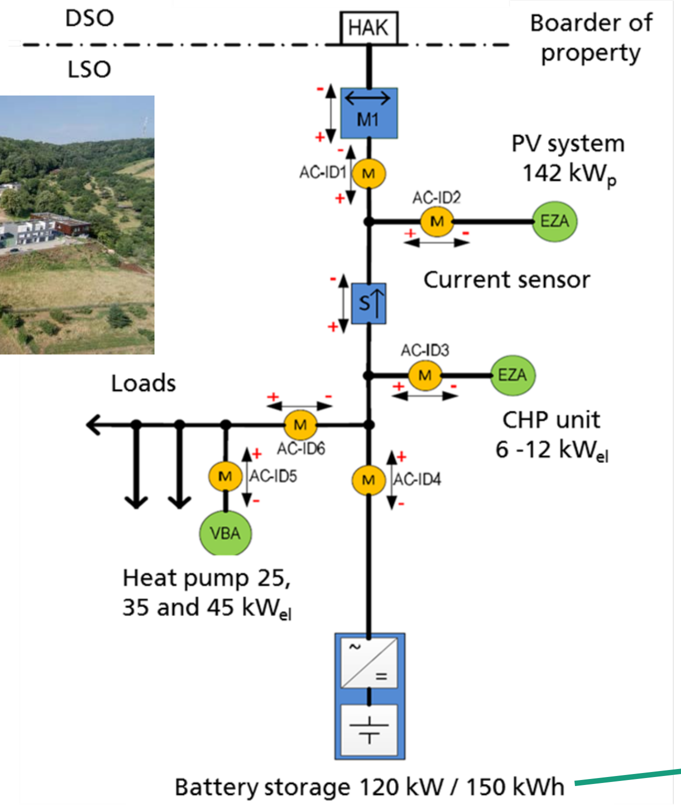
Key factors for storage product and project evaluation

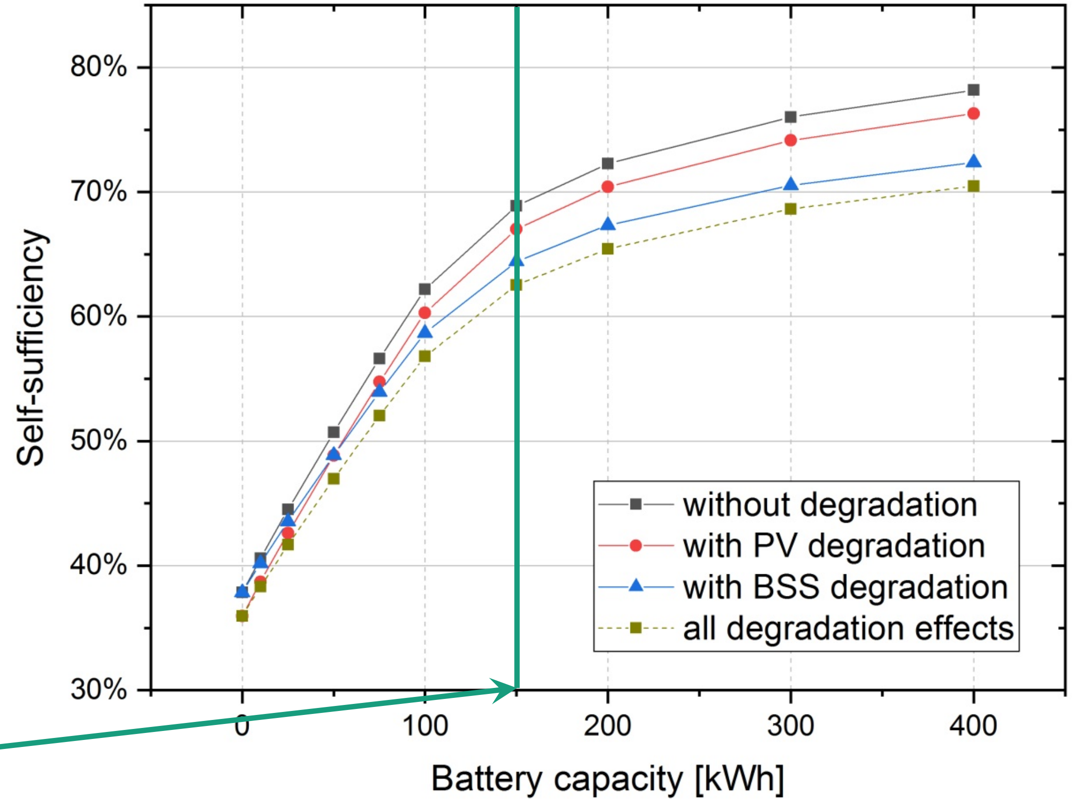
Performance – Effectiveness: Example of a district battery storage

- Simulation based analyses

System concept of district power supply



Reduction of self-sufficiency over time

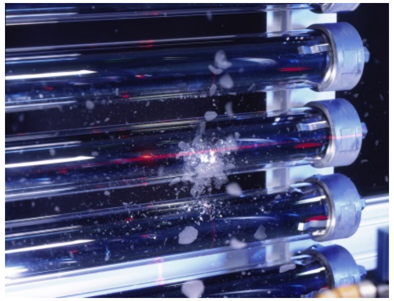
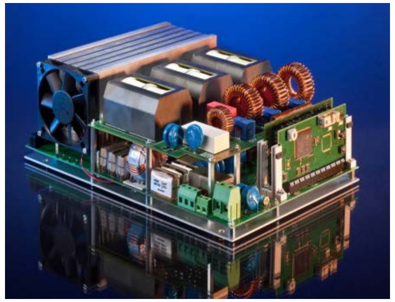
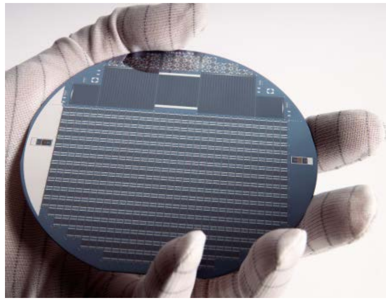


Source: L. Millet et al.: Extensive analysis of photovoltaic battery self-consumption: Evaluation through an innovative district case-study; Applied Physics Reviews, 2019.

Conclusions

- Large-scale integration of fluctuating renewable energies in power supply systems require storage
  - ➢ Technically → Reliability of power supply
  - ➢ Economically → Business models in post feed-in tariff times
  - → Accelerated market growth for battery storage expected !
  - → But: Lack of long-term experiences with new battery technologies !
- Aging has a strong influence on key factors for storage product and project evaluation
  - ➢ Safety: Component and system level as well as functional safety
  - ➢ Reliability: Component and system level as well as consideration of operating conditions
  - ➢ Performance: System efficiency as well as system effectiveness
- Appropriate quality assurance measures are key for risk mitigation

Thanks for your attention !!!

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