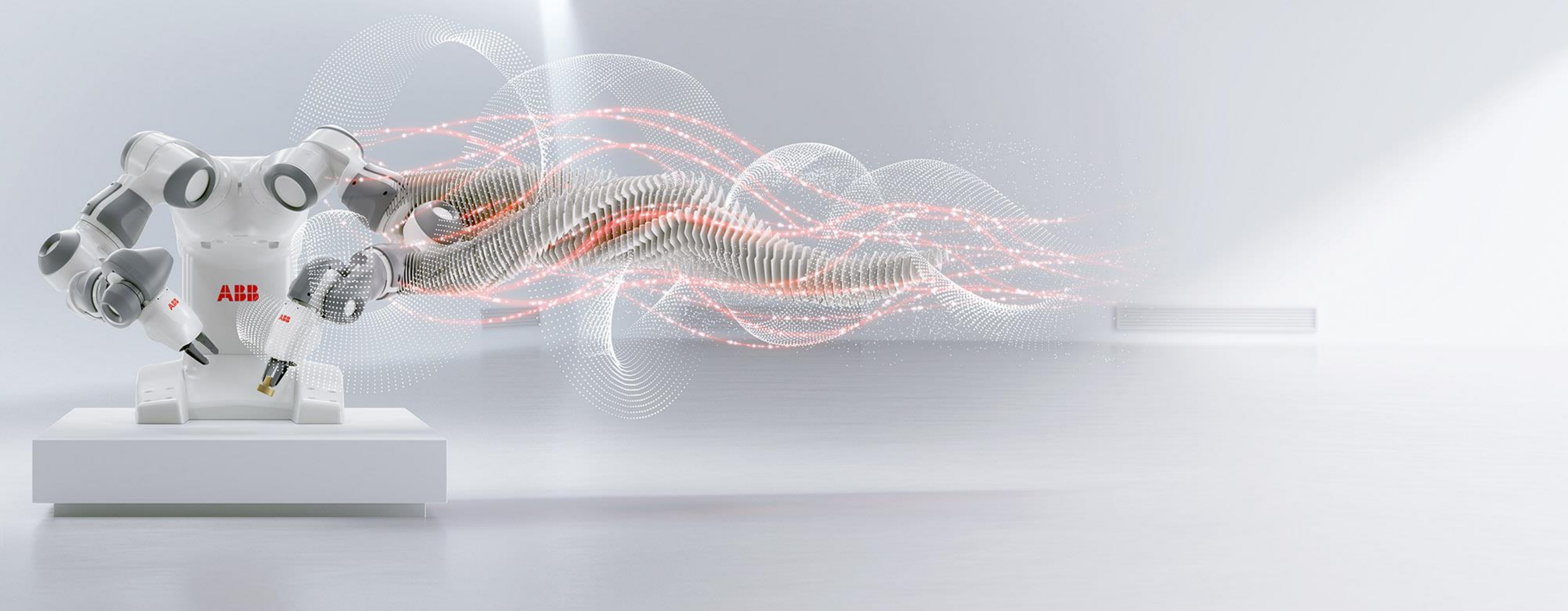


SWISS ELECTROCHEMISTRY SYMPOSIUM, MAY 22, 2019

Battery solutions for emerging applications in the power grid

Daniel Chartouni, ABB Switzerland Ltd, Corporate Research

Agenda (30 minutes)

Application landscape and current examples

- Capacity firming (renewable integration)
- Primary Frequency Regulation
- Residential PV with battery storage

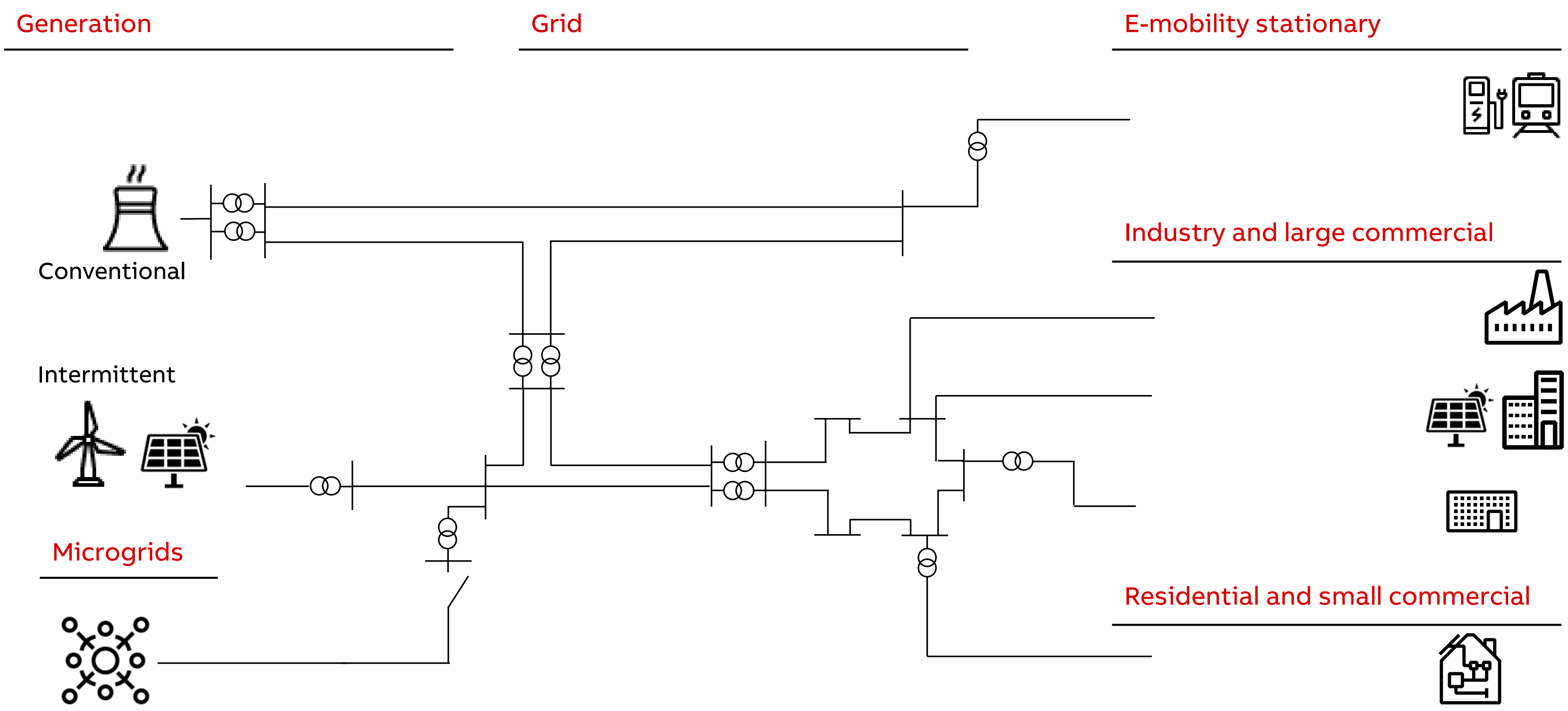
Trends and emerging applications

- Aggregated systems

Summary / Discussion

Energy storage applications

Used today across various industry segments, behind and in front of the meter



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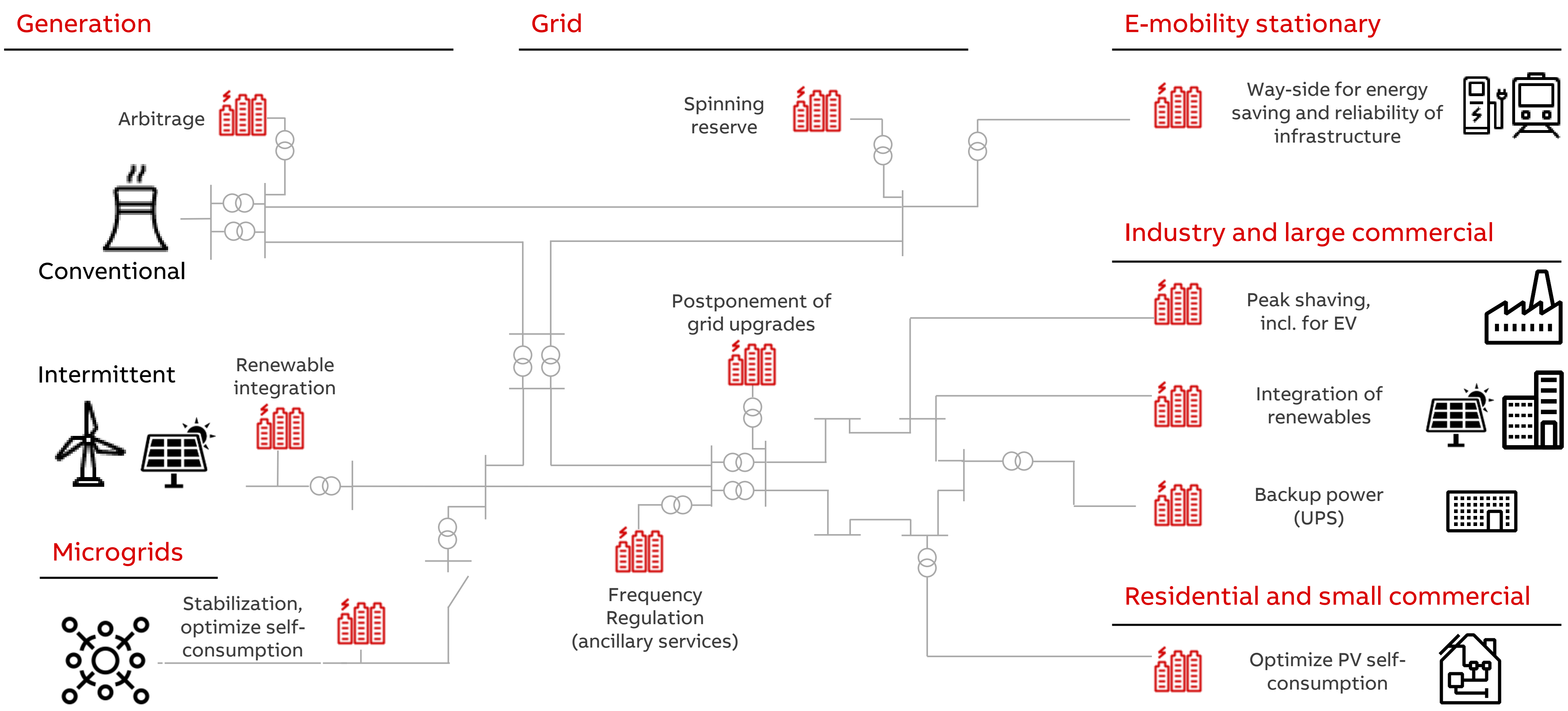

ABB

Energy storage applications

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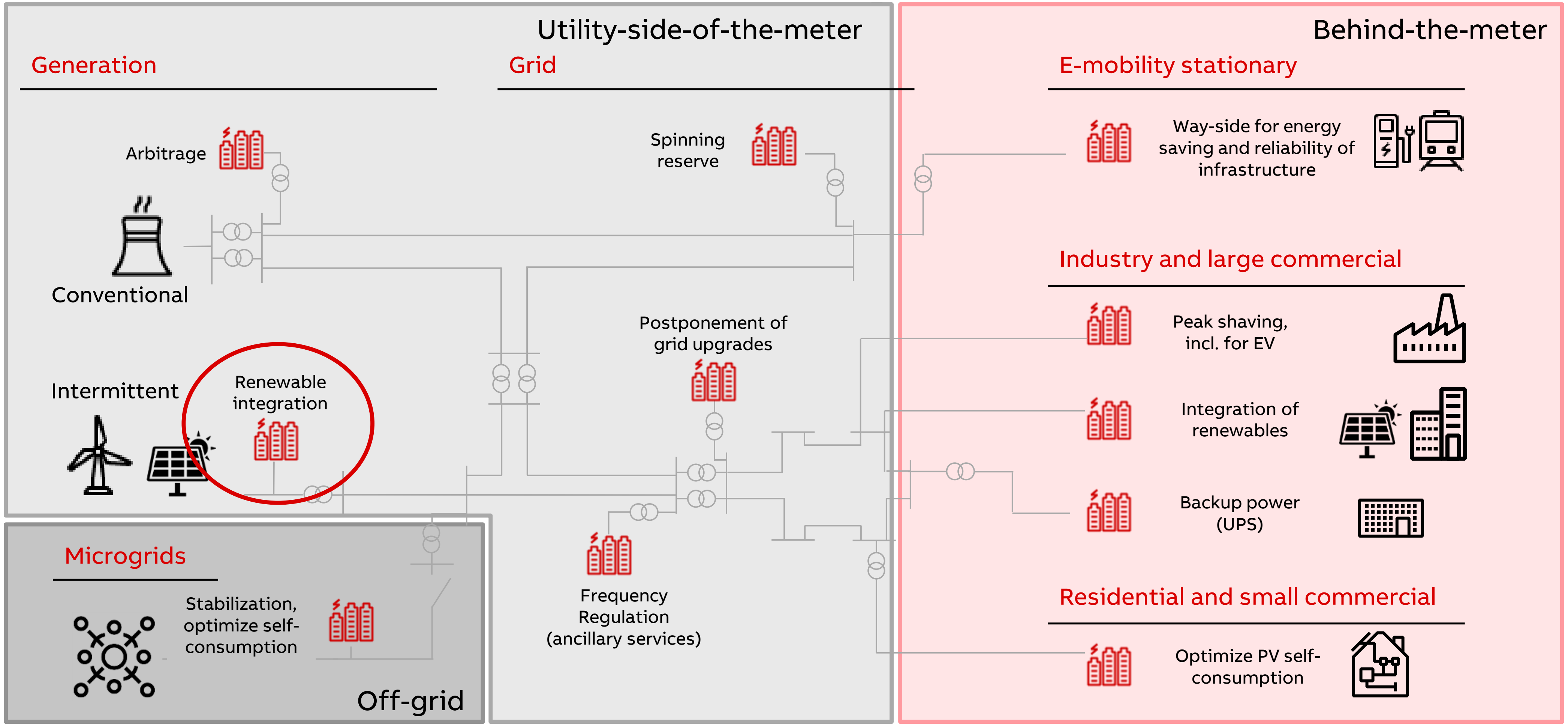


Example of renewable integration (capacity firming of large solar)

BESS Project Chitose Hokkaido—Japan 17 MW

Customer needs

- 28 MW PV grid integration
- Ramp rate control 1%/min—Voltage support—Capacity firming

Project details

- Li-ion batteries
- Installed in 2016

ABB scope

- (4) x 4 MW + (1) x 1 MW outdoor PCS
- PCS inverters, DC contactors, AC circuit breakers
- MV-LV coupling transformer
- MV switchgear
- Local controller integrating PCS, switchgear and MBMS
- Local HMI

Integration of utility scale renewables

Intermittent bulk generation

Capacity firming of intermittent bulk generation

Renewable stabilization:

- Wind: stabilization of large wind farms for dispatchable output
- Solar: balancing of supply and demand (time-shifting)

Value streams

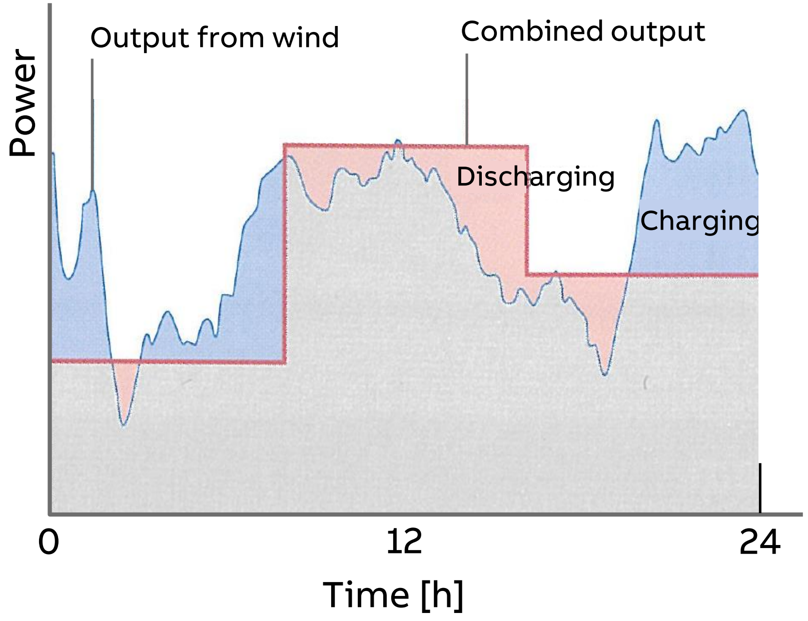
Non-renewable primary energy savings by self consumption increase and avoiding renewable curtailment (Abregelung)

Fossil fuel peaker plant replacement

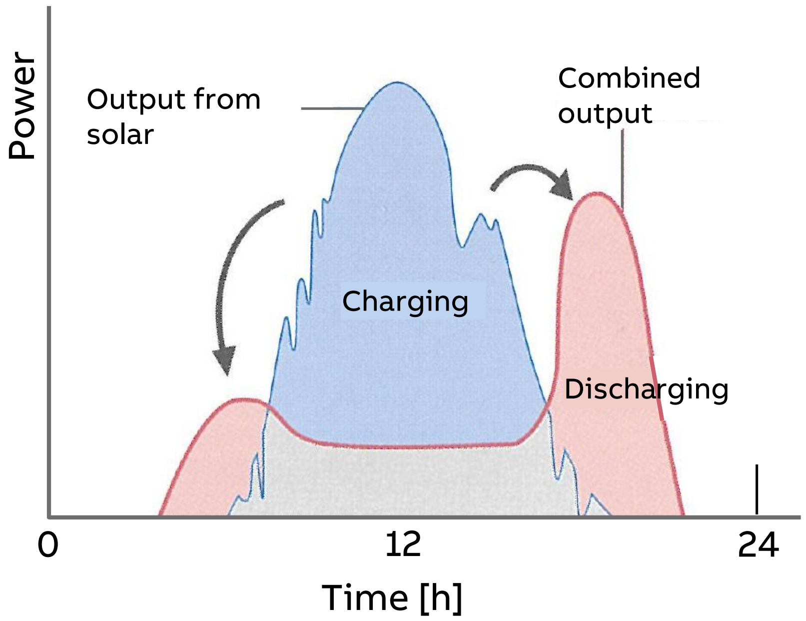
Regulatory requirements:
e.g. Ramp rate control 1%/min

Concepts

Dispatchable output of wind power



Time-shifting of solar power



Source: Graphs adapted from: NGK Insulators, LTD, https://www.ngk.co.jp/nas/

Example of a Sodium-Sulfur BESS to balance supply and demand

BESS in Buzen City, Fukuoka, Kyusyu, Japan

Capacity	50 MW / 300 MWh
Containers	252
Footprint	100 x 140 (m)
Construction	6 months
Commission	March 2016
Grid connection	66 kV
Main purpose	Capacity firming renewable energy (solar)

Source: Photo: Kyusyu Electric Power Co., Inc, https://www.ngk.co.jp/nas/case_studies/buzen/

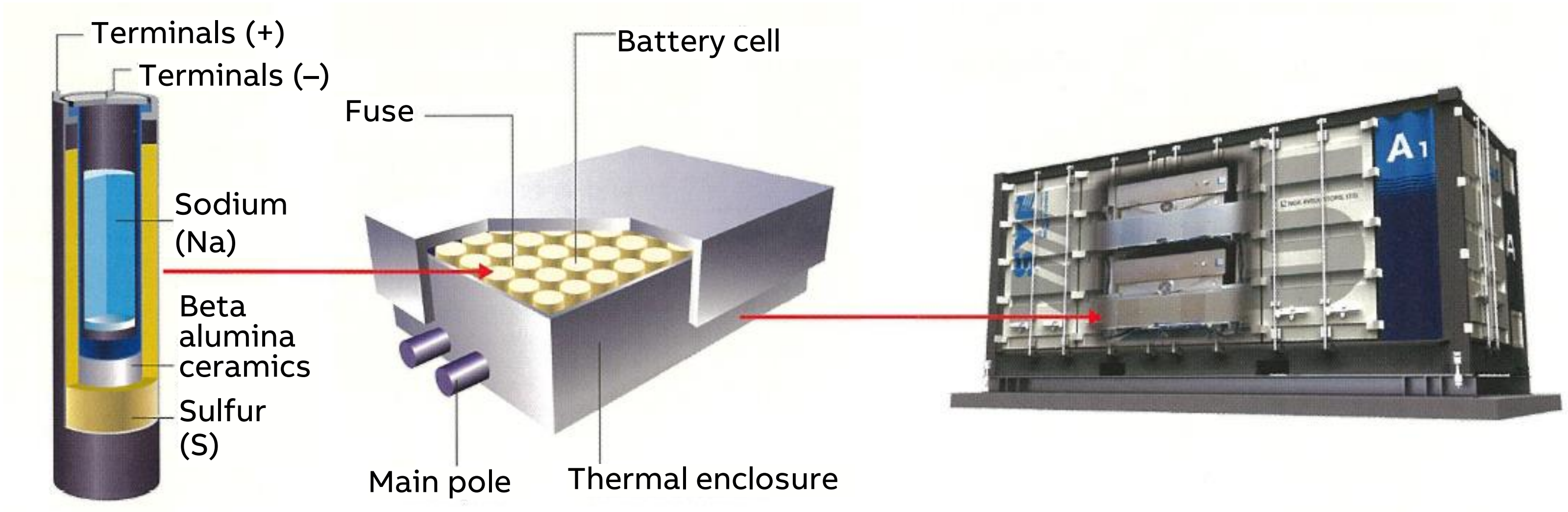
Technology example: Sodium Sulfur (NaS) Battery

Developed for large scale utility-side applications

Typical characteristics

Discharge time	4–10 hours
Power	200 kW – 50 MW
Cycle life Calendar life	4,500 full cycles, 15 years
Battery type	High temperature (320°C) Ceramic electrolyte
Advantage	Abundant base material availability
Disadvantage	Single source (NGK), Scaling: min 200 kW

Battery cell   Module   Battery container



$$2\,Na + x\,S \rightarrow Na_2S_x \quad (3.3 \leq x \leq 5)$$

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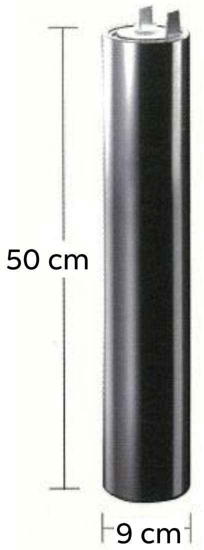
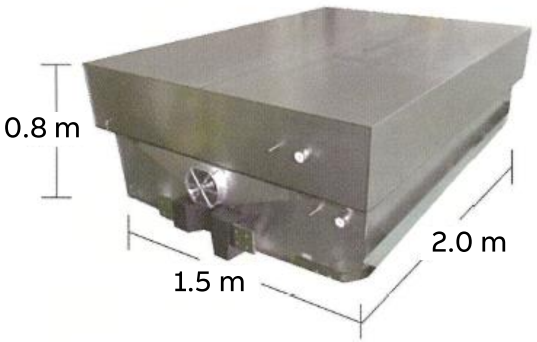
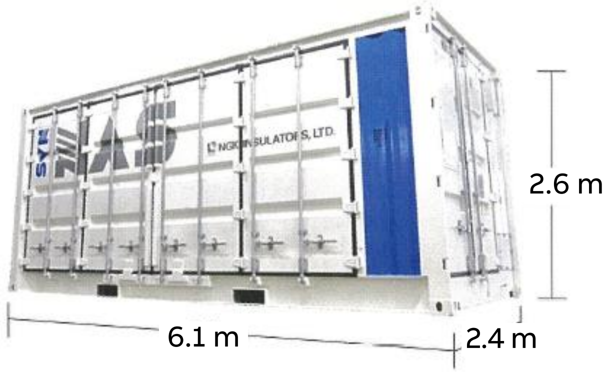


Module



■ 33 kW / 200 kWh

Battery container

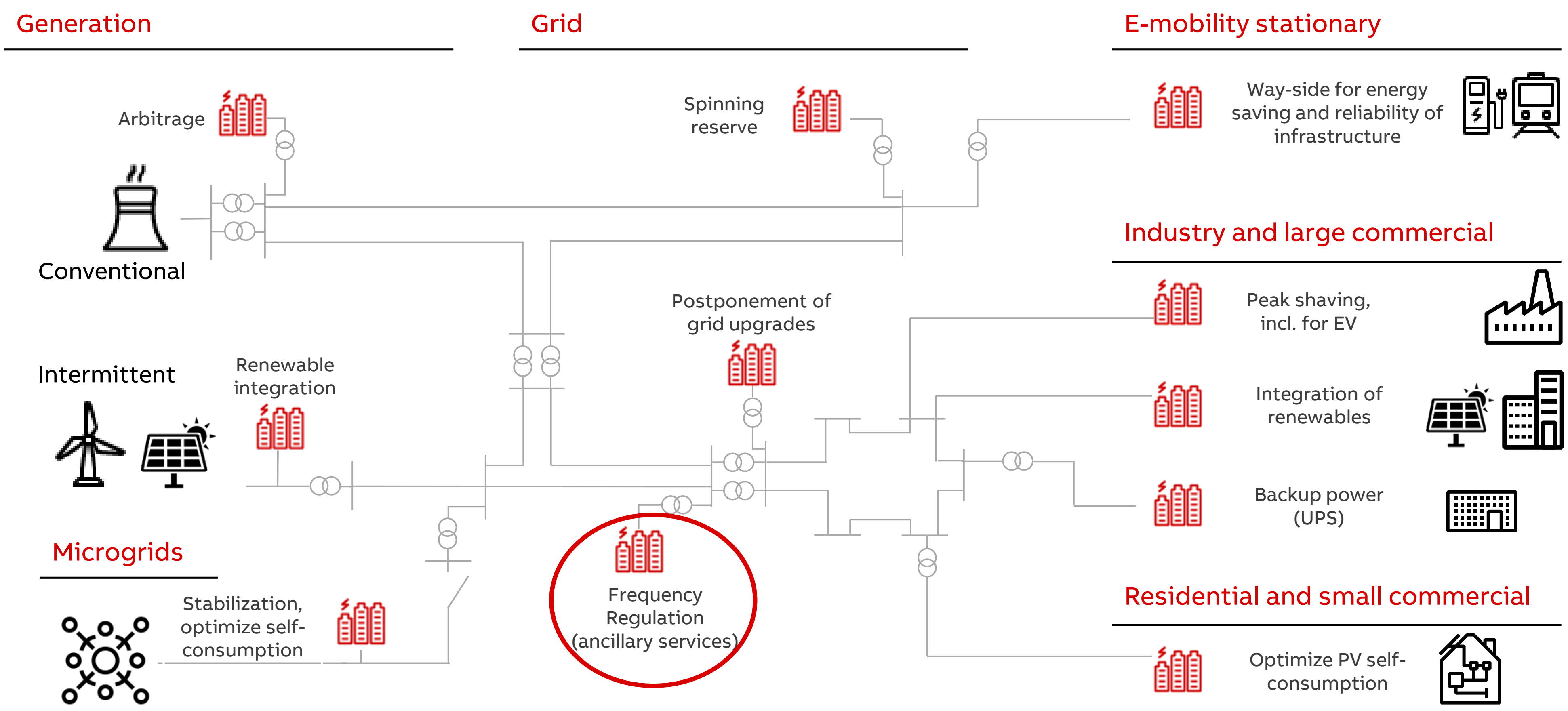


■ 200 kW / 1,200 kWh

 Source: Gauthier Dupont, “Ceramic Batteries, a proven alternative to lithium-ion”, NGK Europe, IRES 2019

Energy storage applications

Used today across various industry segments, behind and in front of the meter

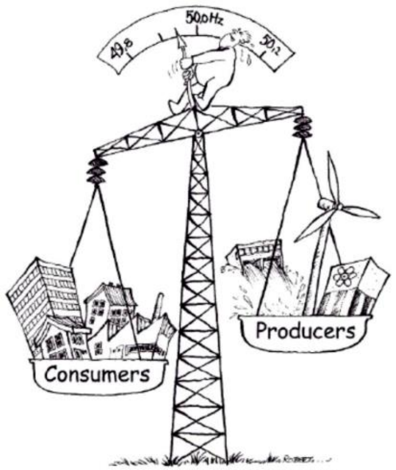


Primary Frequency Regulation

Primary Frequency Regulation

Main purpose

- Keep the balance between electrical load and generation at any instant in order to keep the grid frequency at the reference value
- Done by using reserve power to respond to changes in the grid frequency



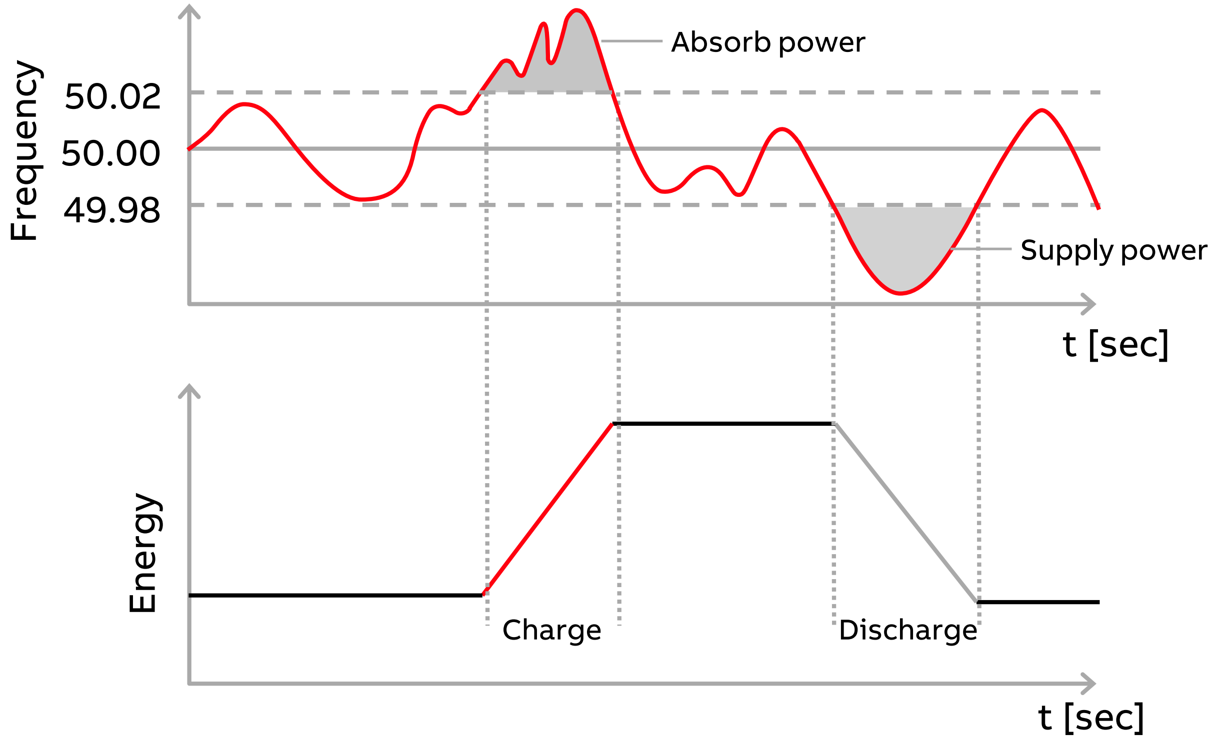
Value stream

- Control reserve is remunerated
- Power only: in $/kW/week

Remarks

- Typical utility-side-of-the-meter application
- Requirement of 1 MW (minimum) and up to 50 MW

Concept



Example of an ABB energy storage solution

Turn-key 1MW Li-ion BESS for Utility EKZ, Switzerland

Customer needs

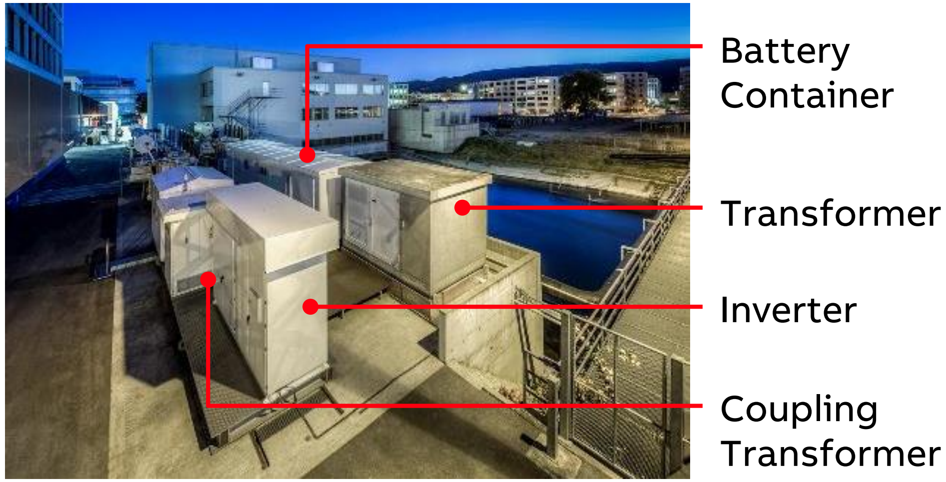
- Frequency and voltage regulation
- Peak shaving
- Islanding capability

ABB Scope

- Turn-key supplier delivering a complete storage system for demonstration purposes
- 1 MW PCS100 converter housed in an outdoor cabinet
- Installed in 2012

Energy storage technology

- Li-ion batteries (250 kWh)




Inside Battery Container

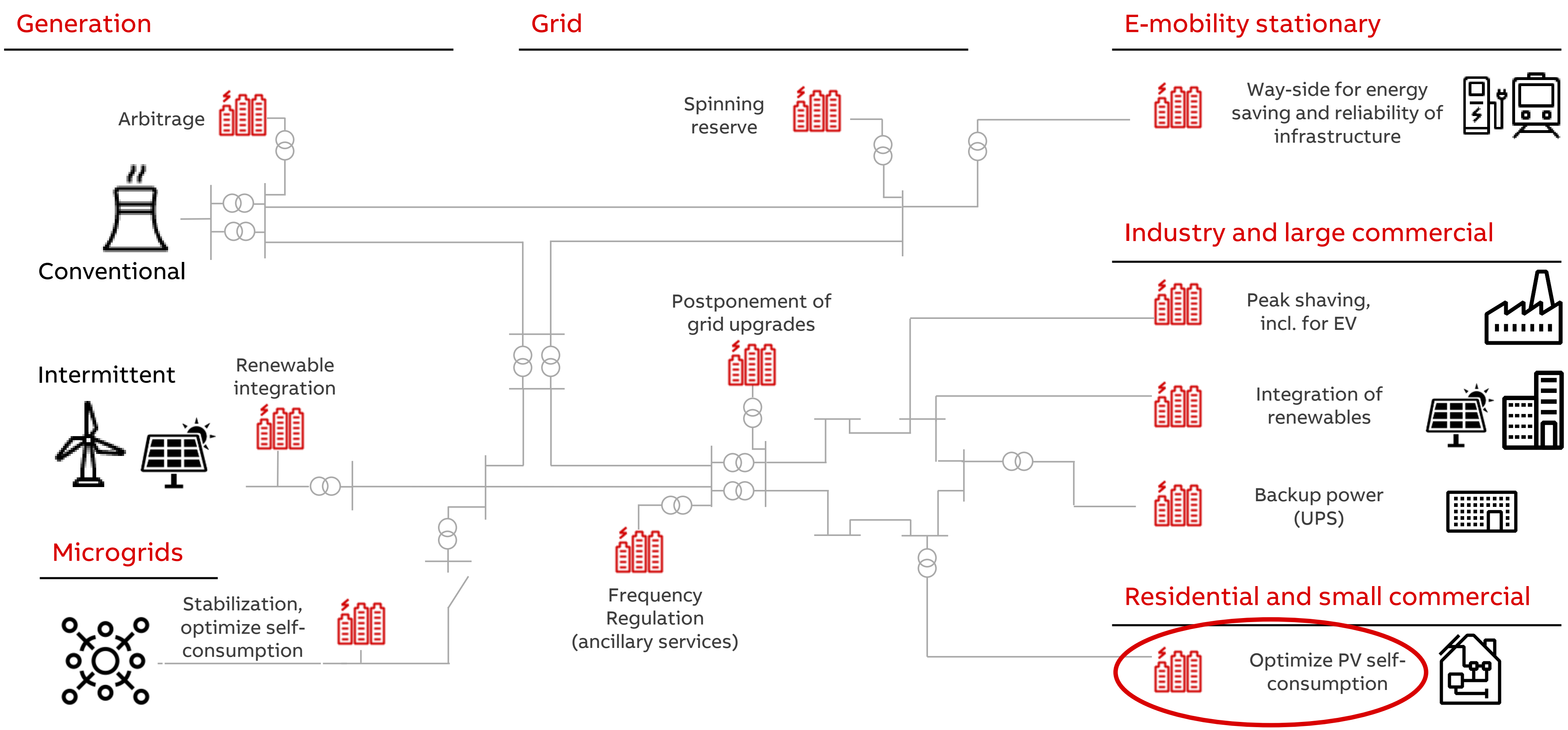

Li-ion battery modules


Control Room


PCS100 modules

Energy storage applications

Used today across various industry segments, behind and in front of the meter



Residential homes with PV and Battery storage

End-customer application

Residential PV with battery storage

Main purpose – main motivation

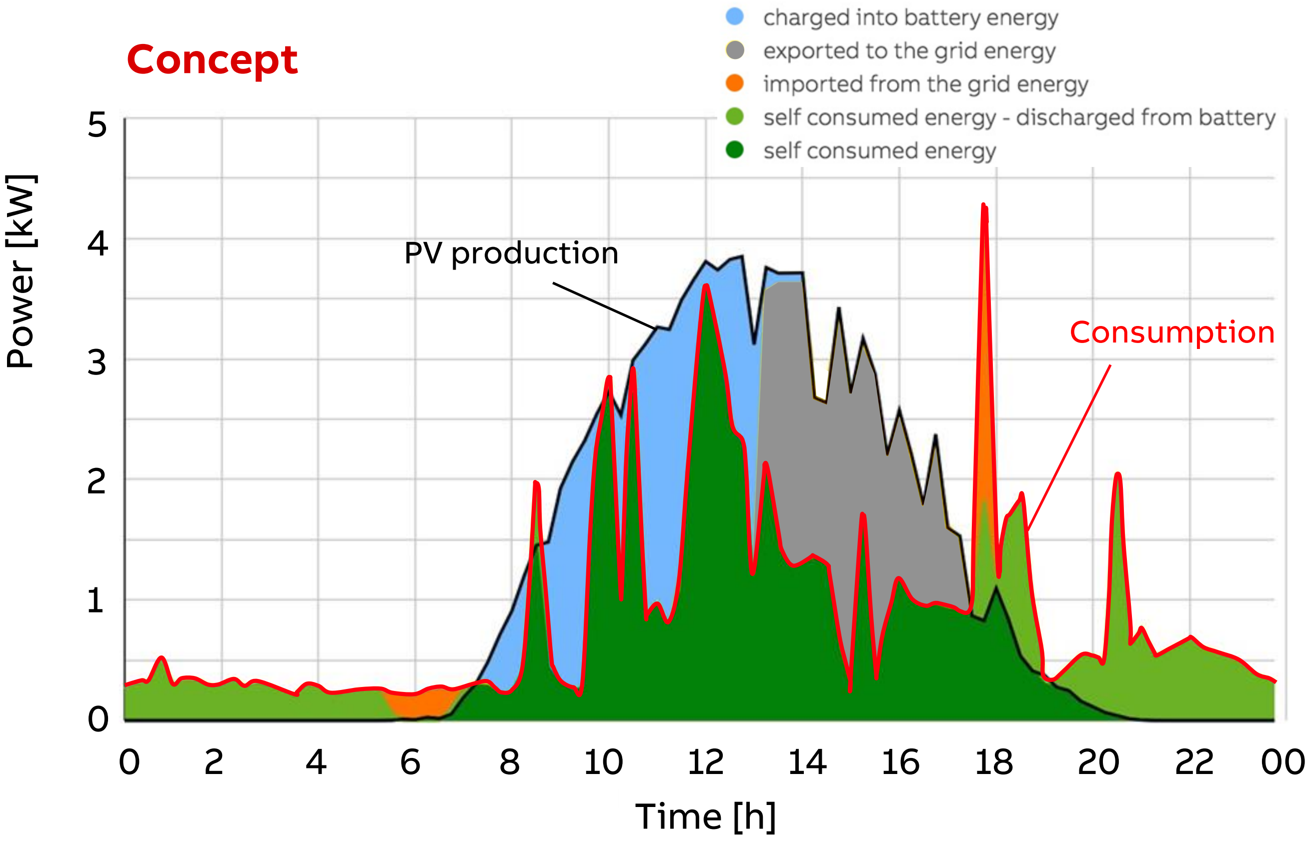
- Maximizing self consumption
- Ecological mind set (support of solar energy)
- Autarchy and independency

Value stream

Difference of electricity cost from local grid and remune-rated price (feed-in tariff)

PV plus Battery storage
Example: REACT 2

Concept



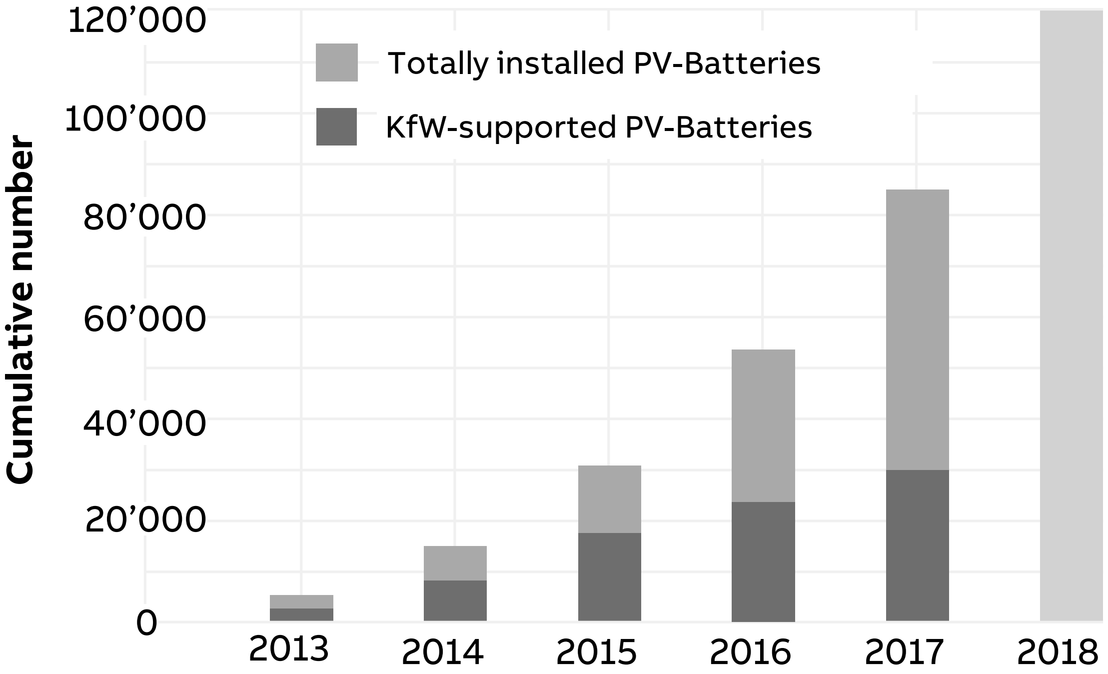
Example (May 15, 2019): REACT 2 Battery solution (3.6 kW, 4 kWh)

Source: www.abb.com/react
http://www.speichermonitoring.de/fileadmin/user_upload/Speichermonitoring_Jahresbericht_2017_ISEA_RWTH_Aachen.pdf

Increase in residential PV with battery storage (e.g. Germany)

2018, accumulated 900 MWh of PV-batteries with total power of 440 MW installed

Cumulative number of installations (2013 - 2018)



Observation in Germany

- Main motivation for the owner
  - Maximizing self consumption
  - Ecological mind set (support of solar energy)
  - Autarchy and independency
- 60% of the new installed PV systems have a Battery in addition
- In total: 940 MWh, 440 MW installed decentrally (End of 2018) in 120’000 installations
- Forecast end of 2019: 1.3 GWh, 600 MW installed

Source: 2013-17 adapted from: http://www.speichermonitoring.de/fileadmin/user_upload/Speichermonitoring_Jahresbericht_2018_ISEA_RWTH_Aachen.pdf courtesy of ISEA RWTH Aachen, and 2018 from https://www.pv-magazine.de/2019/03/12/energy-storage-europe-gigawatt-marke-bei-speichern-bis-ende-2019-in-deutschland-greifbar/, https://www.pv-magazine.de/2019/05/14/eupd-research-sonnen-vor-lg-chem-und-byd-weiter-marktfuehrer-bei-photovoltaik-heimspeichern-in-deutschland/

Residential PV-Battery cost

Consideration

Observation

- Declining cost trend to roughly 1000 $/kWh usable capacity

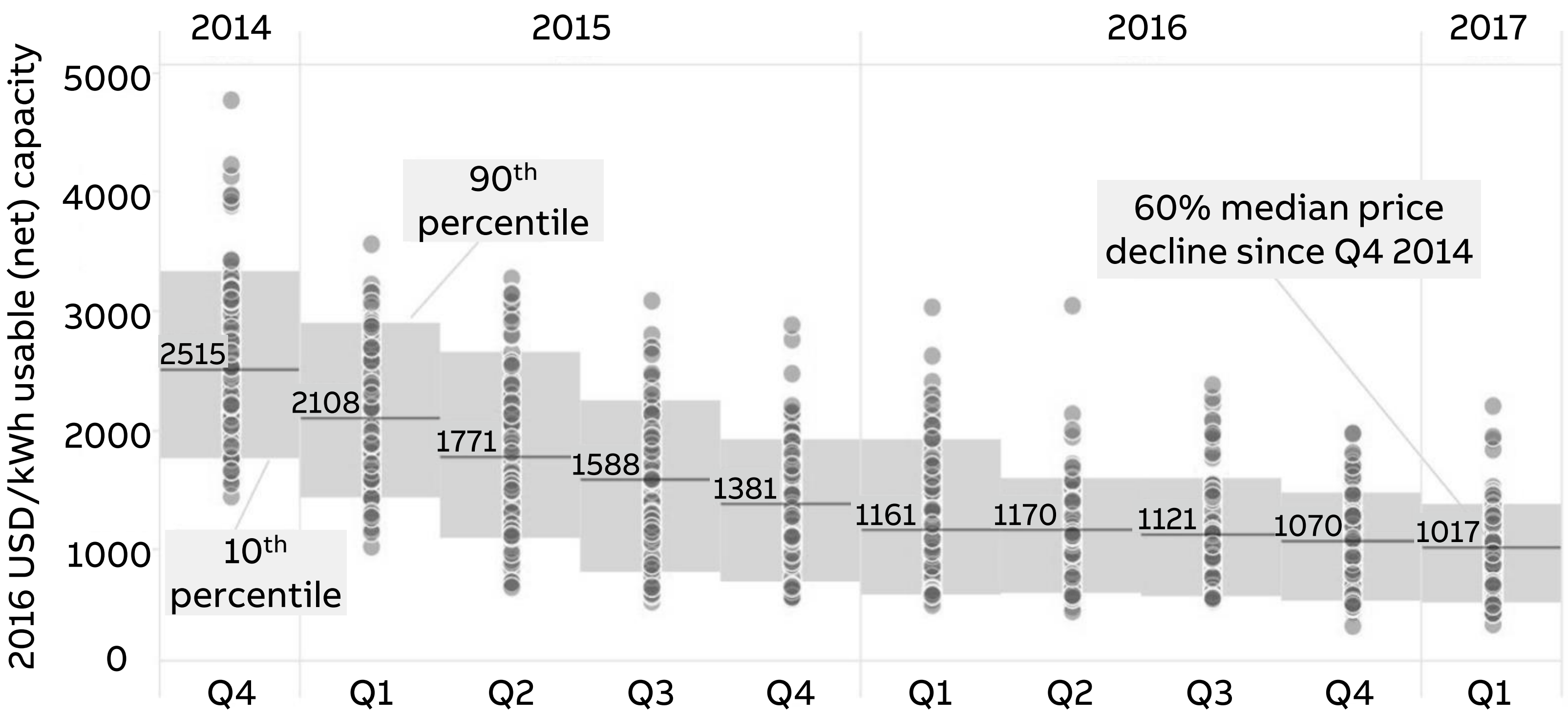
Assumptions

- 250-365 cycles/year
- Lifetime: 10-15 years

Cost per discharged kWh

- 1000$/kWh / # total cycles
  = 0.18-0.40 $/kWh

Residential storage system offers in Germany[1] (Li-ion)



Source: IRENA, ELECTRICITY STORAGE AND RENEWABLES: COSTS AND MARKETS TO 2030, October 2017, https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf

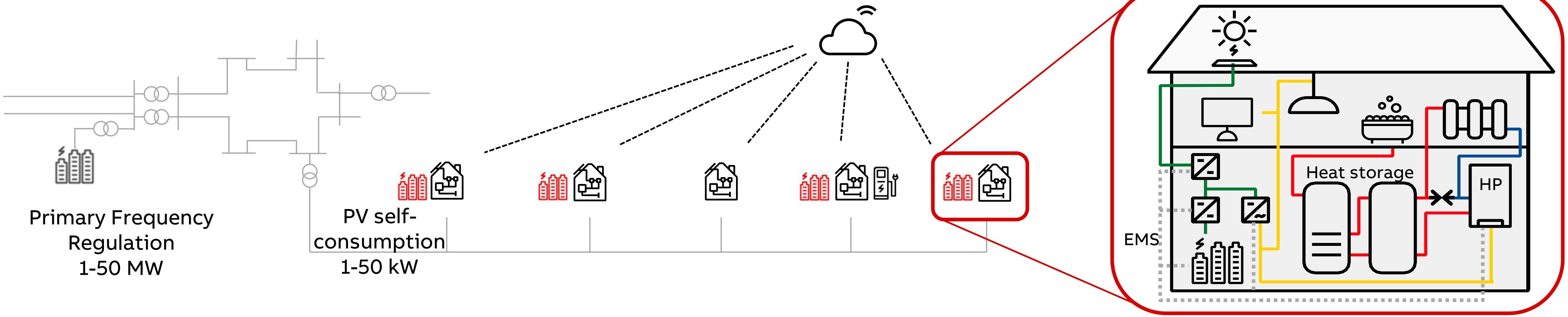
Residential PV with batteries

Observation

- Today, more than 60% of new residential PV installations have a battery in addition
- Battery is in most cases under-utilized in terms of cycling[1]: average installation is 250 cycles/year, i.e. 3750 cycles within 15 years

Development

- From stand-alone product to integrated energy management system (multi-use concept with heat pump, EV charging, load management, etc.)
- From stand alone to cloud connected, aggregated systems



Source: [1] Observation and figure on the right: Georg Angenendt et. al, ISEA, RWTH Aachen, "PV Battery Energy Storage Systems with Power-to-Heat Application: Participation in the Control Reserve market", IRES 2019, Development, see e.g.: https://www.pv-magazine.de/2018/10/30/tennet-praequalifiziert-ampard-speicher-fuer-primaerregelleistung/

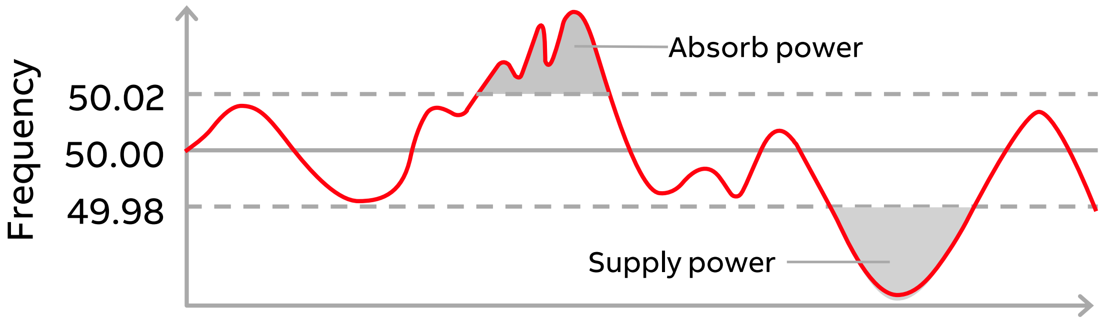
Emerging applications with aggregated systems

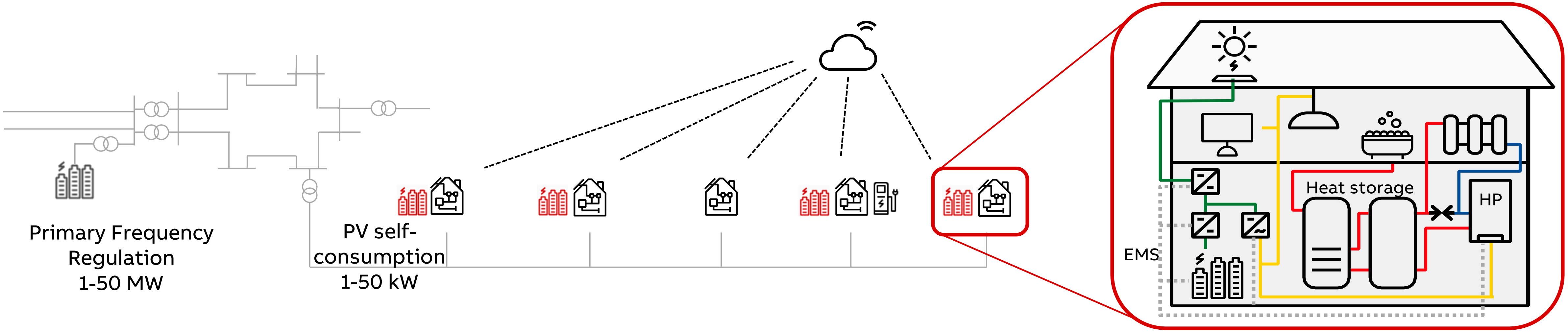
Example of current discussions: PV-batteries used for primary frequency regulation?

Combination of:
PV self-consumption AND primary frequency regulation

For Primary Frequency regulation

- Service has to be provided for a week
- Delivered in positive and negative direction
- 30 minute criteria for prequalification





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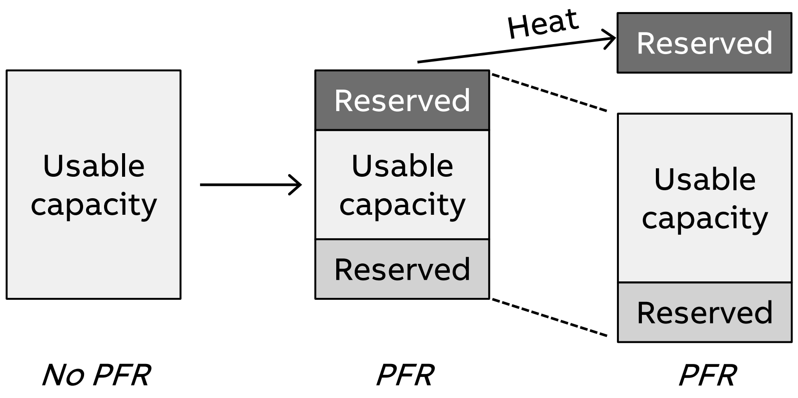

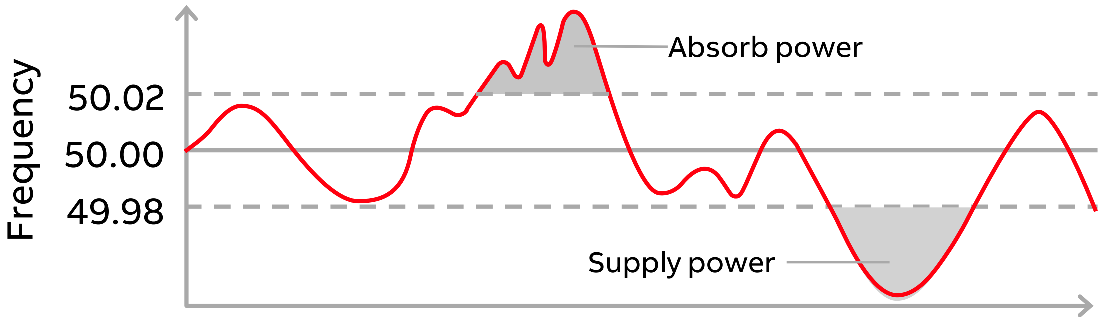

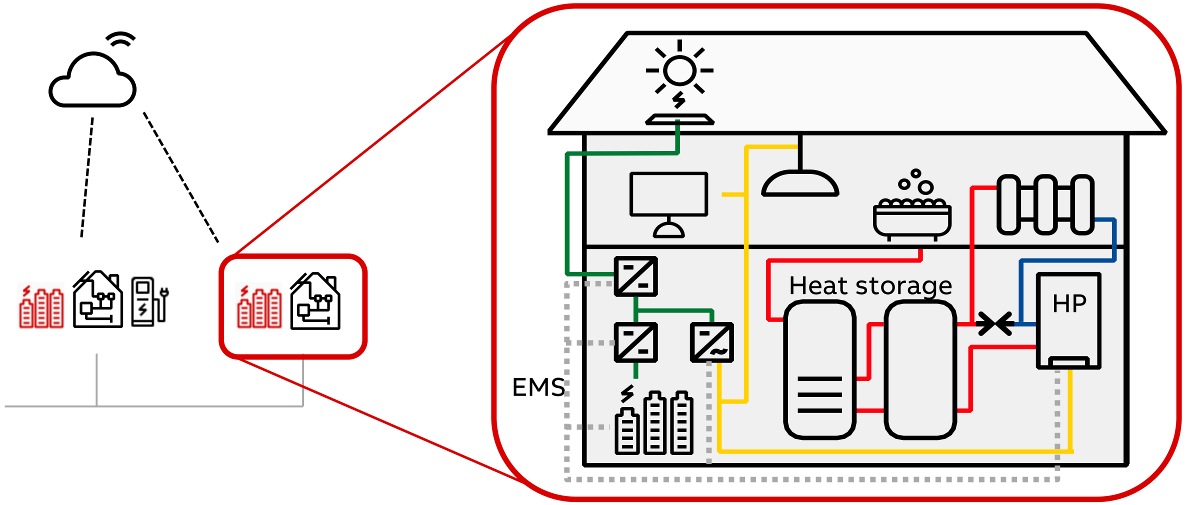

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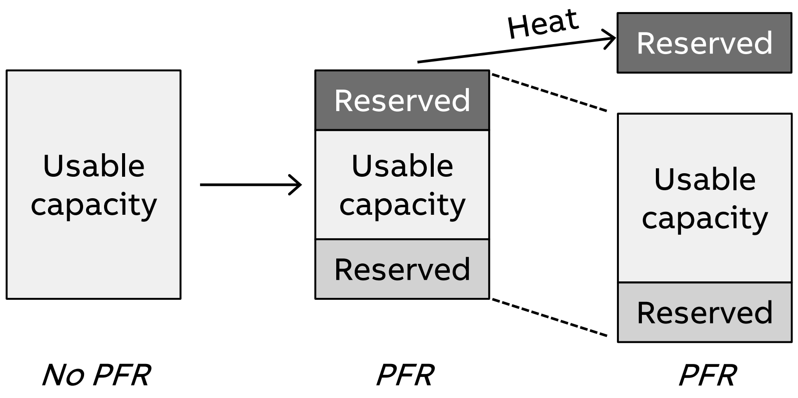
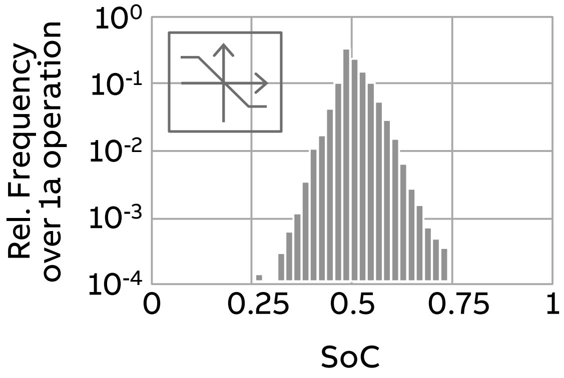


Battery stress factor: average cycling conditions

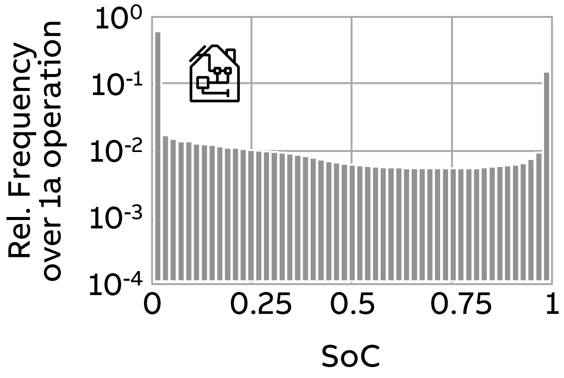
Primary Frequency Regulation



Typical full equivalent cycles (FEC) for PFR:

200-250 $cycles_{FEC}$ /year

PV-BESS (self consumption)



Typical full equivalent cycles (FEC) for PV-BESS:

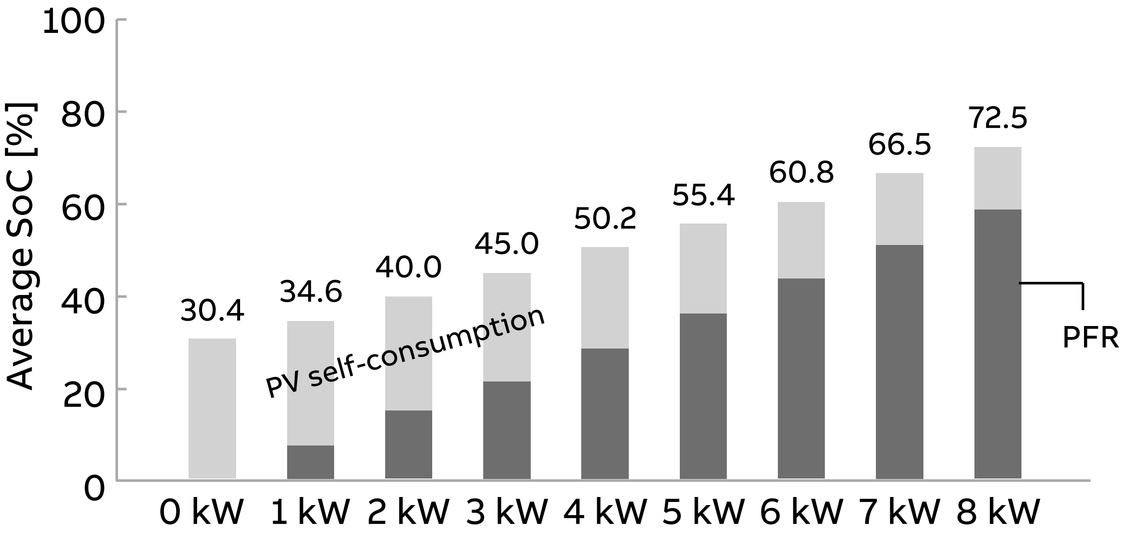
250-365 $cycles_{FEC}$ /year

Source: Left: Georg Angenendt et. al, ISEA, RWTH Aachen, "PV Battery Energy Storage Systems with Power-to-Heat Application: Participation in the Control Reserve market", IRES 2019. Right: Holger H. Hesse et. al, TU Munich, "Topology and Efficiency Analysis for Utility-Scale Battery Storage Systems", IRES 2019

Emerging applications with aggregated systems

Example of current discussions

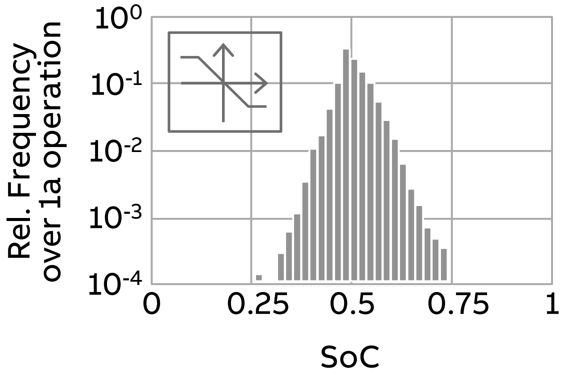
Battery stress factor: average state of charge[1] (SoC)



Example with a 10 kWp PV-system and 10 kWh PV-Battery

Battery stress factor: average cycling conditions

Primary Frequency Regulation



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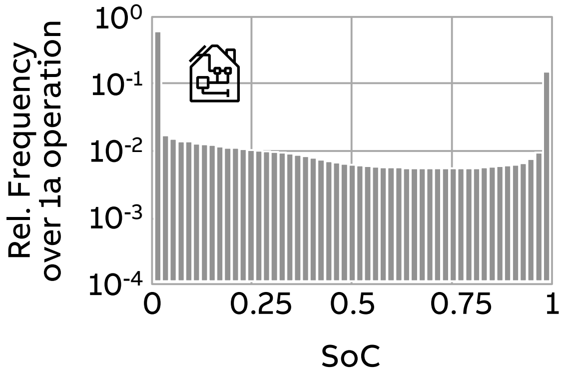


Typical full equivalent cycles (FEC) for PV-BESS:

250-365 cycles_{FEC} /year

In this example battery life is almost unchanged up to 5 kW PFR due to two compensating effects: higher average SoC (reduction in lifetime) vs. more favorable cycling conditions (increase in life time)

Source: Left: [1] Adapted from Fig 6 in: Georg Angenendt et. al, RWTH Aachen, "Einfluss der zusätzlichen Nutzung von PV-Batteriespeichern zur Regelenergiebereitstellung auf die Batteriealterung", available at: https://www.researchgate.net/publication/326919932. Right: Holger H. Hesse et. al, TU Munich, "Topology and Efficiency Analysis for Utility-Scale Battery Storage Systems", IRES 2019

Emerging applications with aggregated systems

Example of current discussions

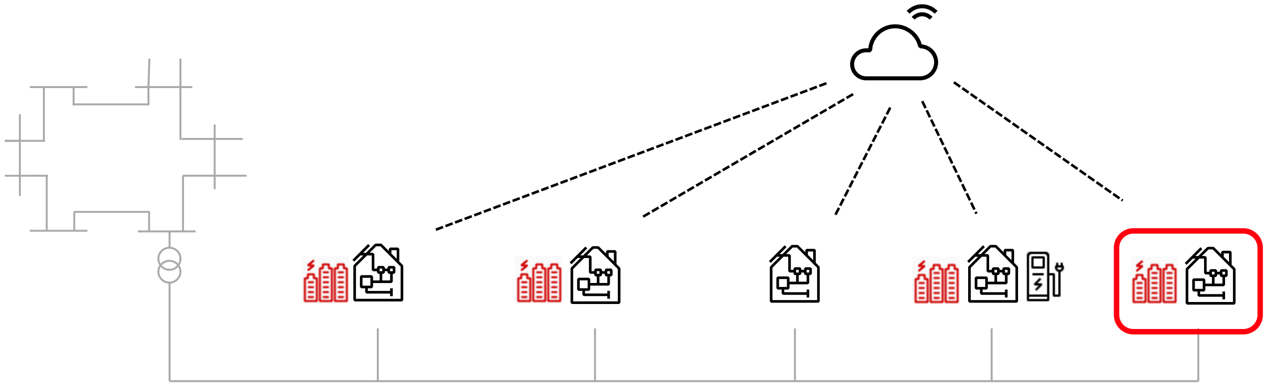
Combination of:
PV self-consumption AND primary frequency regulation

Discussion:

– The combination seems technically viable
– Participation on the control reserve markets can enhance economics of integrated homes
– Integrated homes become more and more economically feasible

Challenges:

– Decreasing remuneration of control reserve
– Costs for market participation and communication
– Allocation of revenues due to regulatory issues



Aggregated systems might become more and more important in future electrification systems

Source: Georg Angenendt et. al, ISEA, RWTH Aachen, "PV Battery Energy Storage Systems with Power-to-Heat Application: Participation in the Control Reserve market", IRES 2019

Vision: The future is Solar – with Batteries

Example: Kapaia installation in 2017, Hawaii, USA

- 13 MW Solar PV, 52 MWh Li-ion battery
- Application: power generation on an island grid
- Completed by Tesla in 2017, awarded a 20 year contract at 13.9 cents/kWh
- Lower than cost of local diesel (15.5 cents/kWh), and half what consumers paid in Dec 2016 (27.7 cents/ kWh)

https://www.bloomberg.com/news/articles/2017-03-08/tesla-completes-hawaii-storage-project-that-sells-solar-at-night

Summary

Battery storage systems are increasingly important

- Integration of intermittent renewables
- Power quality and self sufficiency

Observations

- Massive production increase of Li-Ion capacities for electric vehicles
  As a result: declining Li-ion battery cost
- Increase of decentralized PV-battery systems, and also increase of large scale BESS connected to wind and solar farms

Trends / Discussion

- Aggregated systems of small distributed devices might become increasingly important

ABB