BATTERY STORAGE

OPPORTUNITIES, CHALLENGES AND MEASURES FOR RISK MITIGATION

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AGENDA

- Introduction to battery R&D of Fraunhofer ISE
- Classification of energy storage technologies
- Market developments
- Market segments of stationary battery storage
  - Examples of transmission level
  - Examples of distribution level
  - Examples of customer level
- Key factors affecting bankability and insurability of PV + storage projects
- Quality assurance supporting risk mitigation
- Conclusions

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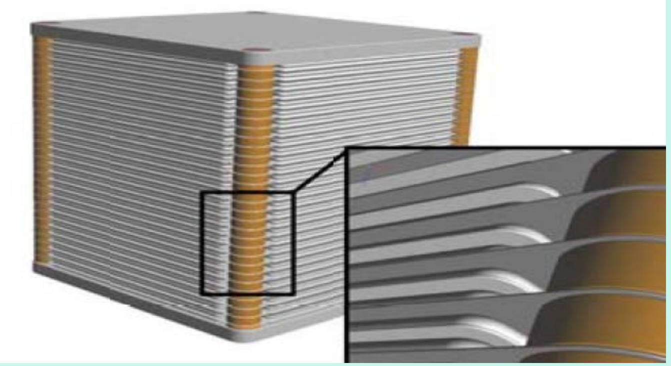
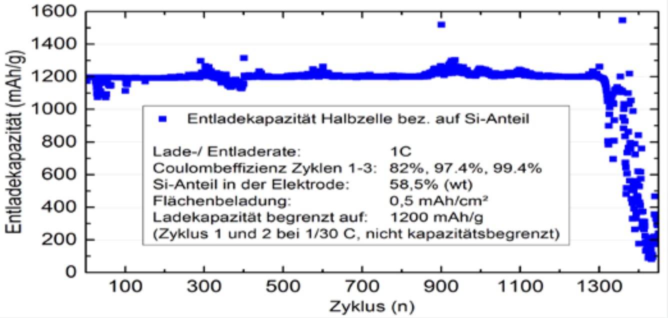
Battery cells

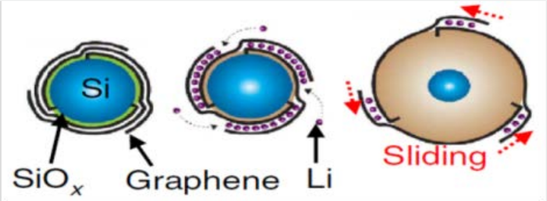
Current focus topics of Fraunhofer ISE

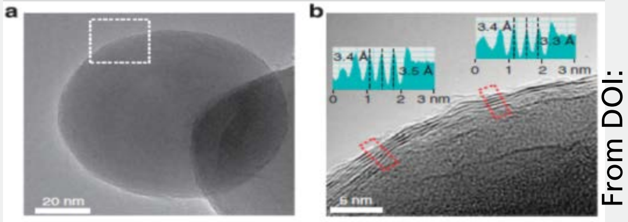
Aqueous batteries for stationary applications



Silicon based anodes as *drop-in replacement* for lithium-ion battery cells

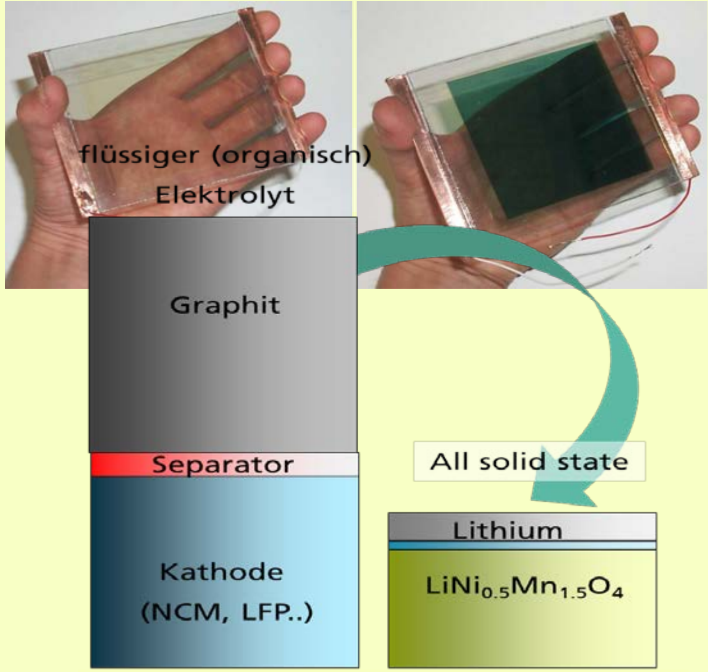






From DOI: 10.1038/ncomms8393

New materials and process technology for *solid state* batteries



Up to 300 Wh/kg **~ 650 Wh/kg**

Up to 850 Wh/l **~ 1700 Wh/l**

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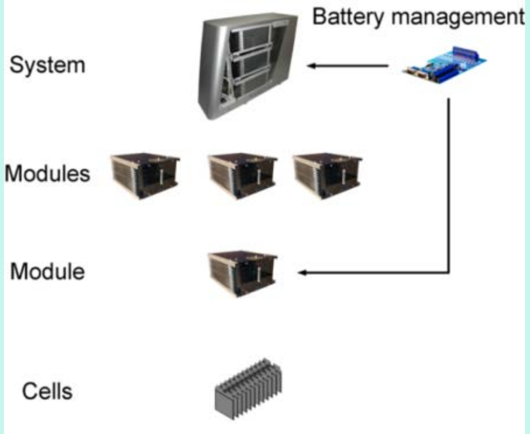
Battery systems and applications
R&D and services of Fraunhofer ISE

Battery system technology
From cells to systems



- Cell characterization
- Module and system design
- Battery management
- Thermal management
- Algorithms for state estimation and life time prediction
- Optimized charging and operating control strategies

Storage applications
System design, integration and quality assurance


Photo: CSIRO. Off-grid power supply for SKA1 low radio telescope

- Consultancy during planning phase
- System design and analysis
- Simulation based storage sizing
- Elaboration of specifications
- Energy management systems
- Site inspections and testing
- Monitoring

Testing
Electrical, thermal, mechanical

- Safety: Components, systems including functional safety
- Aging: Calendric, cyclic
- Performance: Efficiency and effectiveness
- Reliability: Consideration of operating conditions and system performance with aged components

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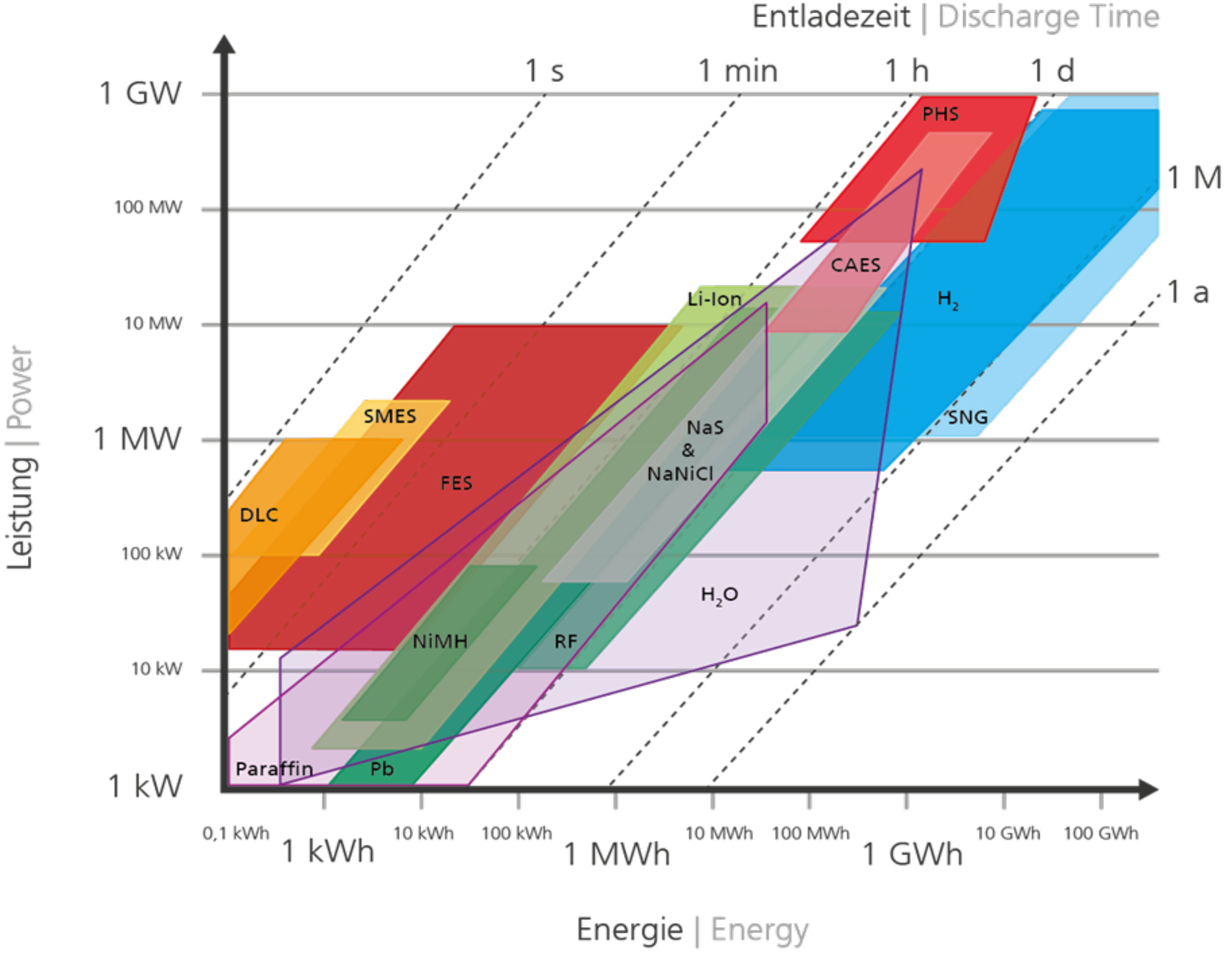
Classification of energy storage technologies

ENERGIESPEICHER | ENERGY STORAGE



elektrisch | electrical
- **DLC** Doppelschichtkondensator | Double Layer Capacitor
- **SMES** Supraleitende Spule | Superconducting Magnetic Energy Storage

mechanisch | mechanical
- **CAES** Druckluftspeicherkraftwerk | Compressed Air Energy Storage
- **PHS** Pumpspeicherkraftwerk | Pumped Hydro Storage
- **FES** Schwungmassespeicher | Flywheel Energy Storage

elektrochemisch | electrochemical
- Sekundärbatterien | Secondary Batteries
  - **Li-Ion** Lithium-Ionen | Lithium Ion
  - **NaNiCl** Natrium-Nickelchlorid | Sodium Nickel Chloride
  - **NaS** Natrium-Schwefel | Sodium Sulphur
  - **NiMH** Nickel-Metallhydrid | Nickel Metal Hydride
  - **Pb** Blei | Lead Acid
- Flow-Batterien | Flow Batteries
  - **RF** Redox-Flow | Redox Flow

chemisch | chemical
- **H_2** Wasserstoff | Hydrogen
- **SNG** Synthetisches Methan | Synthetic Natural Gas

thermisch | thermal
- **H_2O** Wasser (sensibel, Erhöhung der Temperatur) | water (sensitive, increase of temperature)
- **Paraffin** latent (konstante Temperatur bei Phasenübergang) | latent (constant temperature during phase transition)

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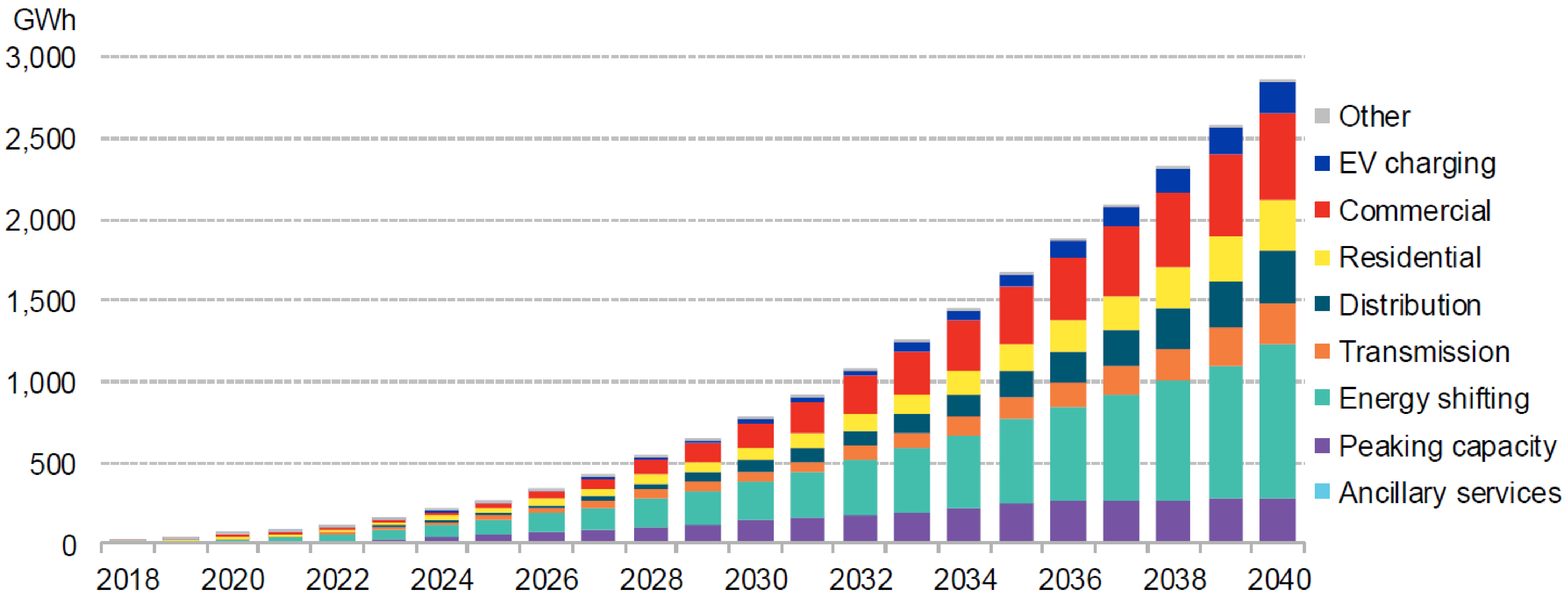
Market developments

Prognosis for global cumulative stationary battery storage deployments



Source: BloombergNEF, 2019.

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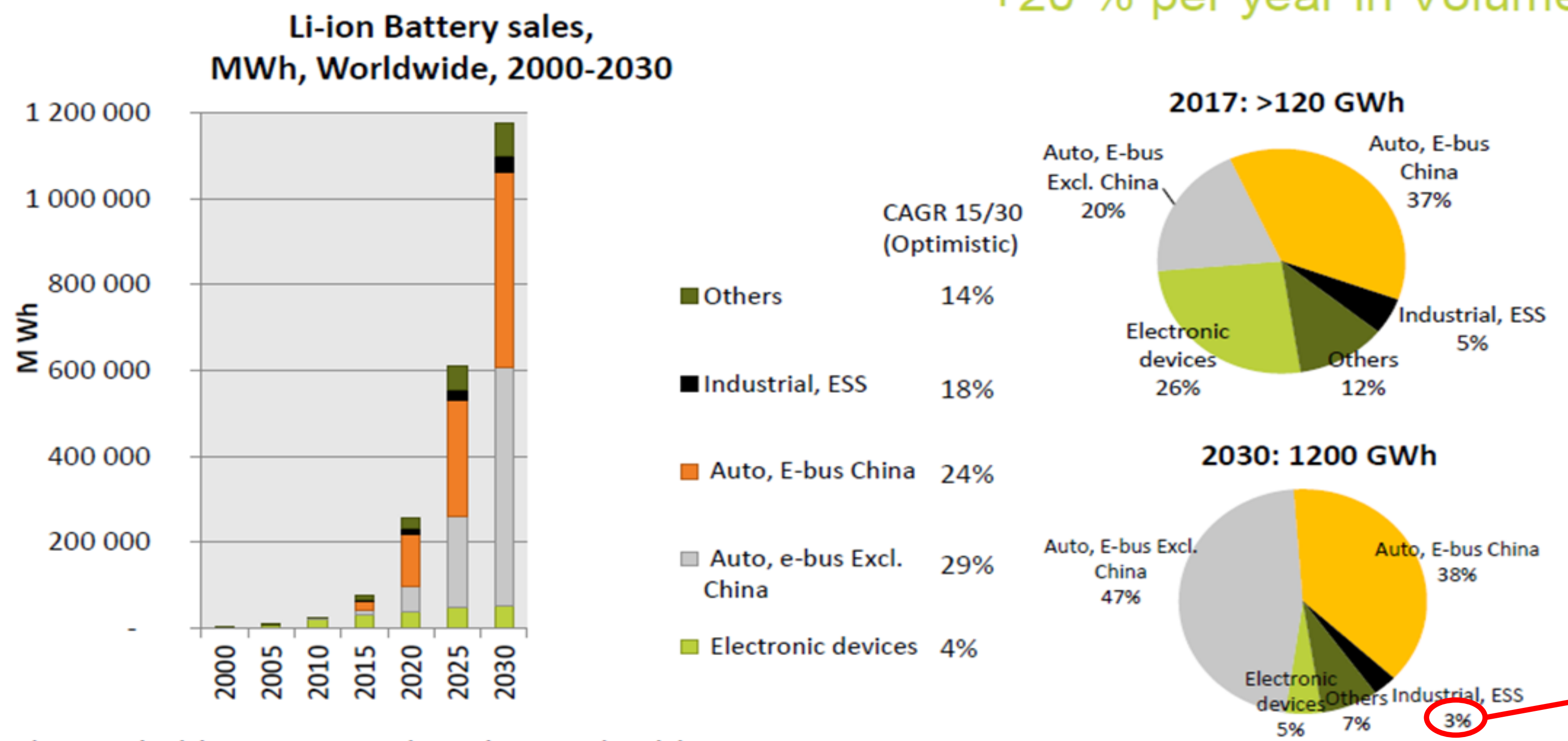
Market developments

Prognosis for lithium-ion batteries – Global volumes

From 120 GWh in 2017 to >1,2 TWh

CAGR 2015/2030
+20 % per year in Volume



Others: medical devices, power tools, gardening tools, e-bikes...

Growth from ~ 120 GWh to ~ 1.2 TWh with an average annual increase of 20 %

~ 36 GWh per year !!!

➔ Stationary applications still of interest for manufacturers of lithium-ion cells ?

➔ Market options for alternative stationary battery technologies ?

Source: AVICENNE Energy, 2019.

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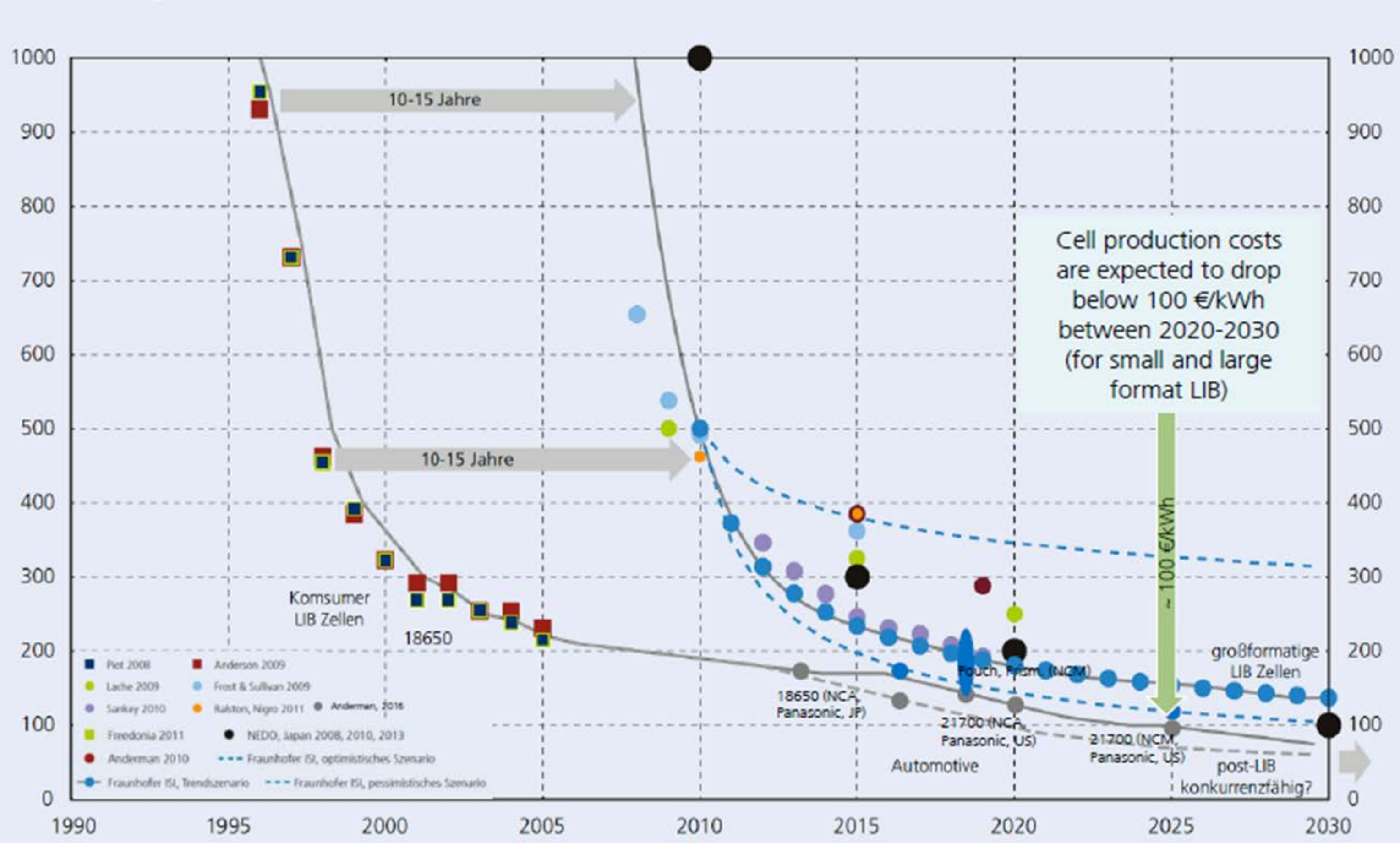
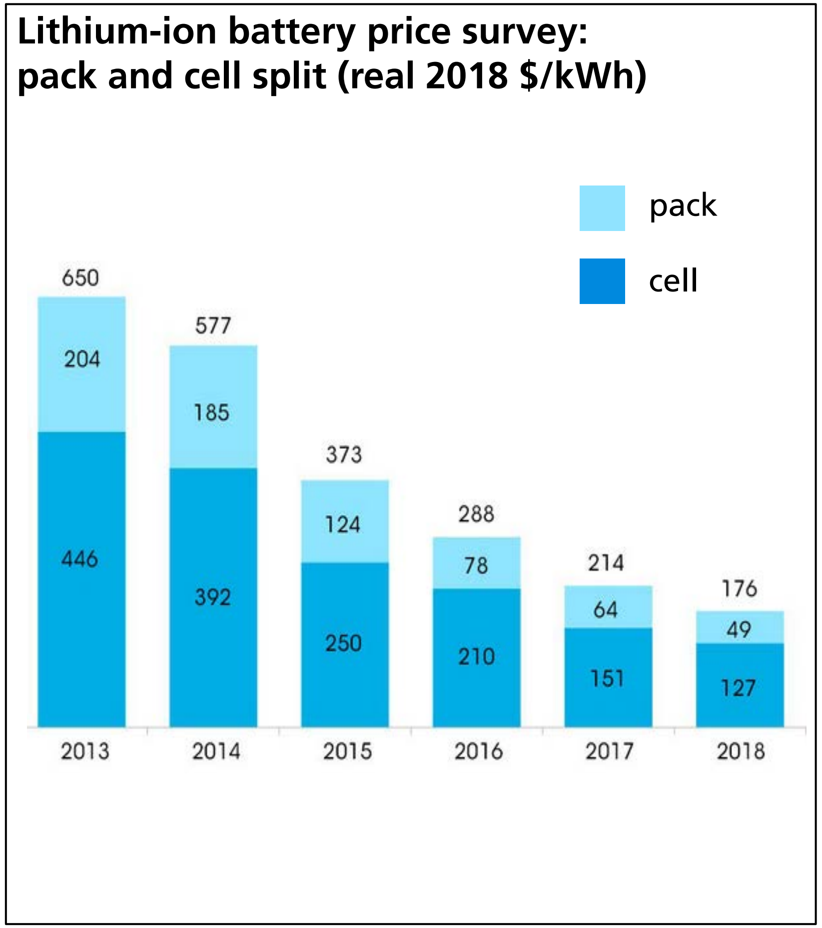
Market developments

Prognosis for lithium-ion batteries – Costs



Source: A. Thielmann: Battery technology monitoring and roadmapping 2030+, ees Munich, 2017.



Source: BloombergNEF, 2019.

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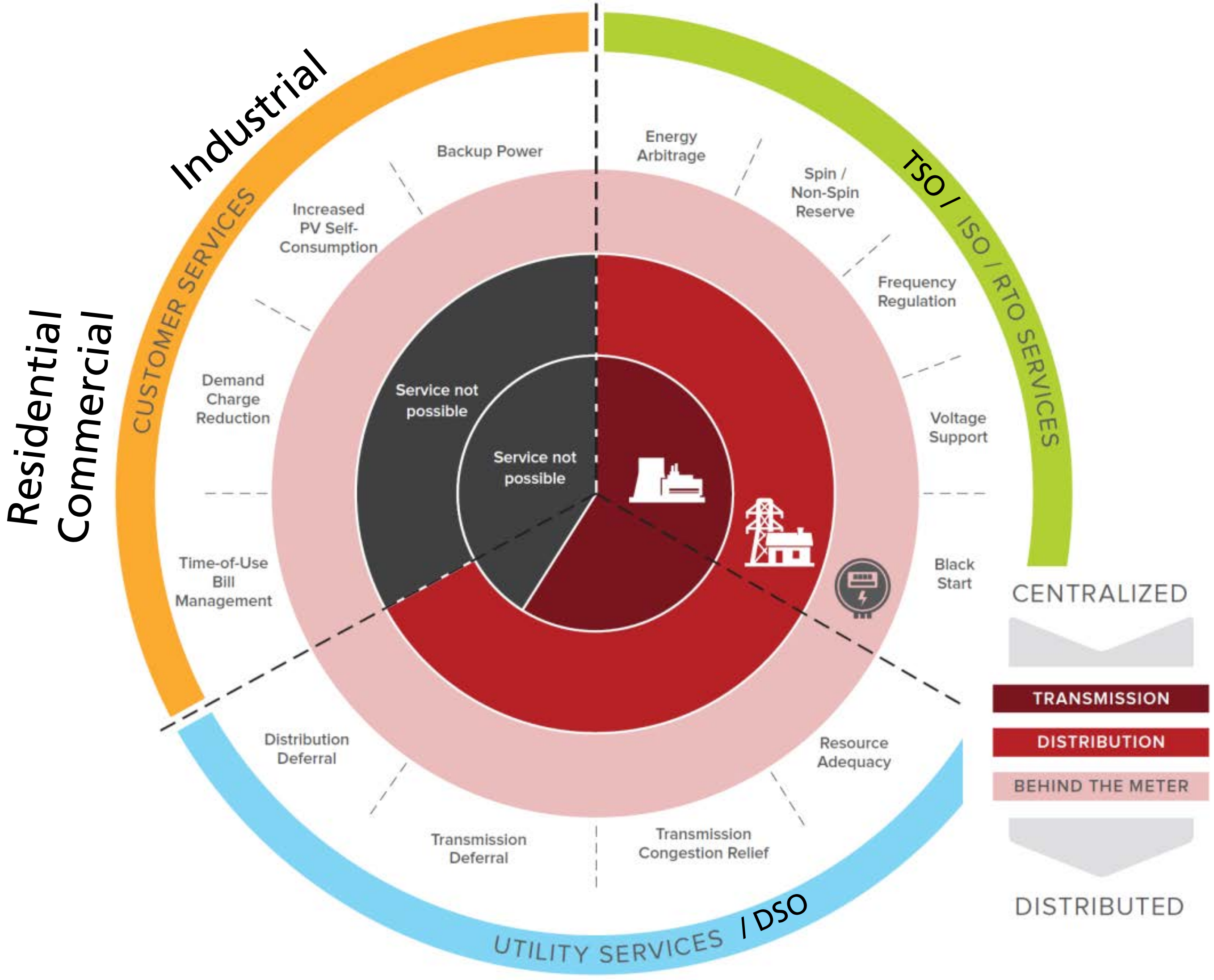
Market segments of stationary battery storage

Batteries can provide up to 13 services to three stakeholder groups



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

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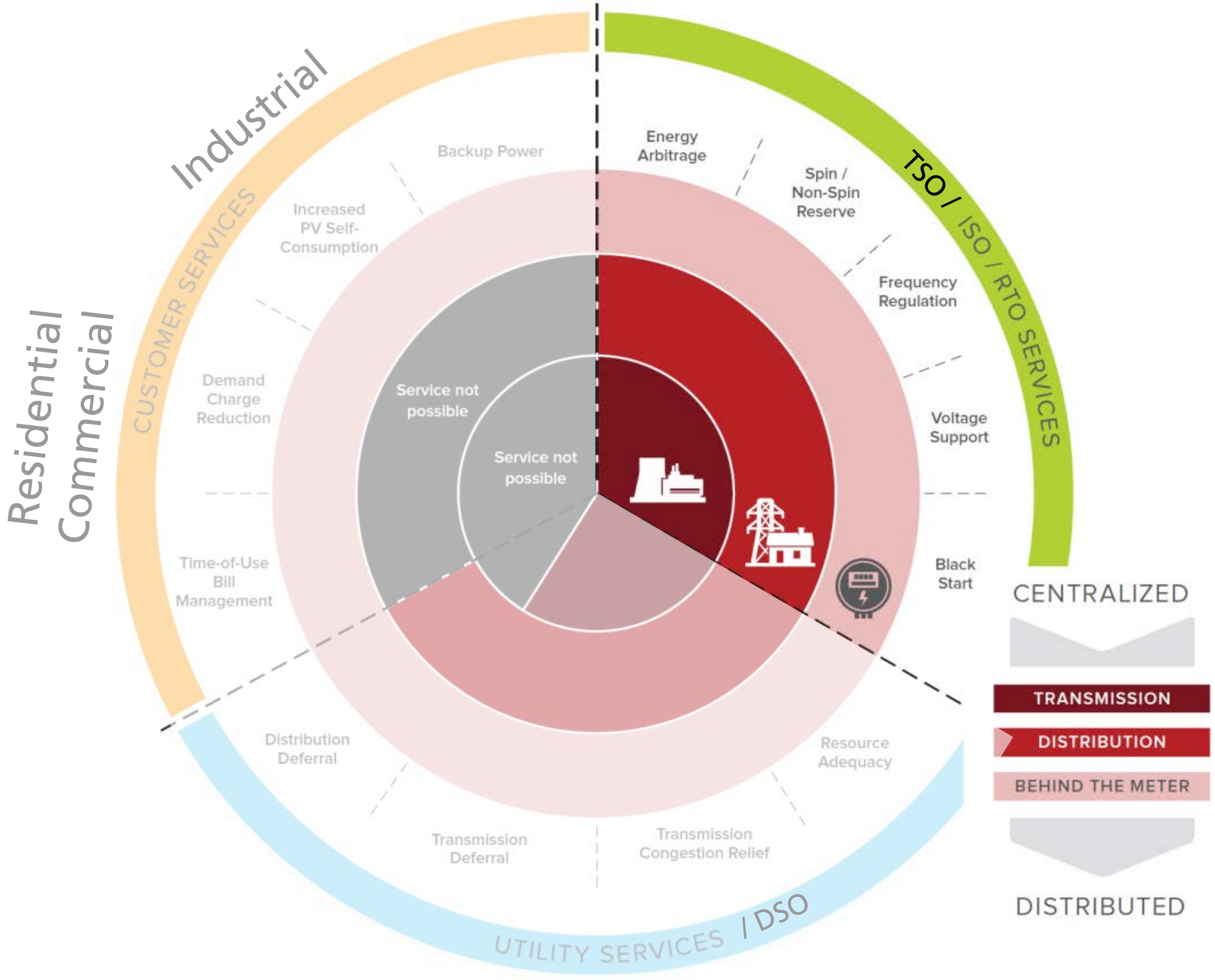
Market segments of stationary battery storage
Transmission level

Batteries can provide up to 13 services to three stakeholder groups



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

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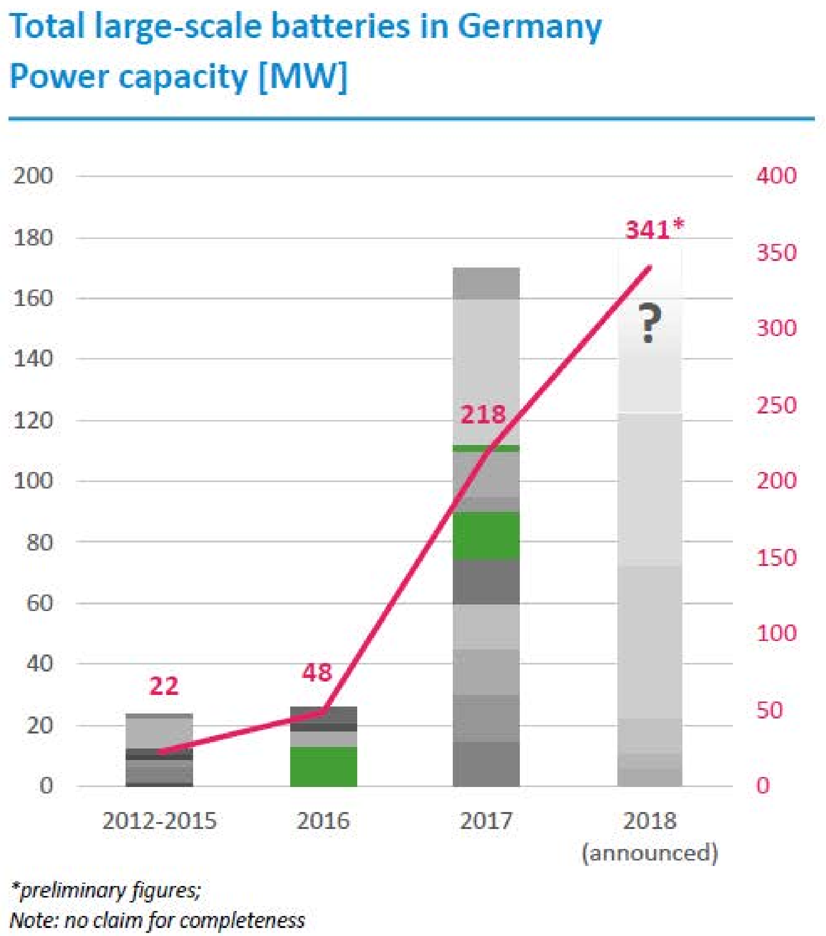
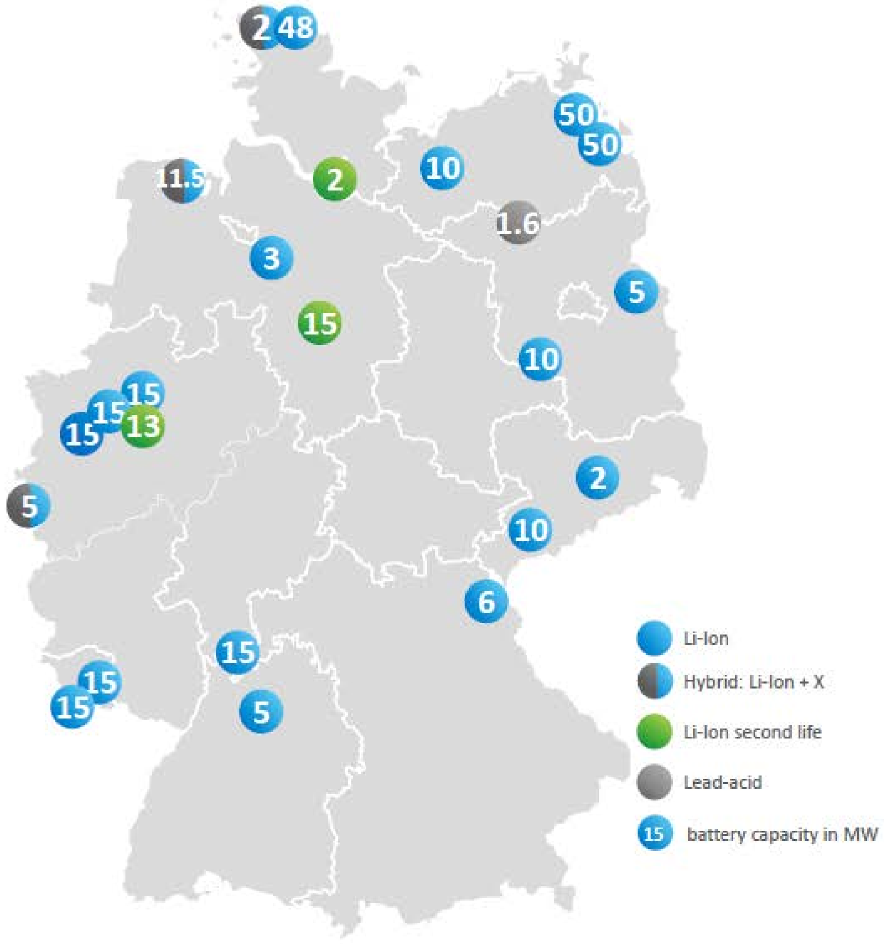
Market segments of stationary battery storage

Transmission level – Example: Primary control power in Germany





Source: A. Bräutigam: Business models for energy storage in Germany and hot spot markets, ees conference, Munich 2017.

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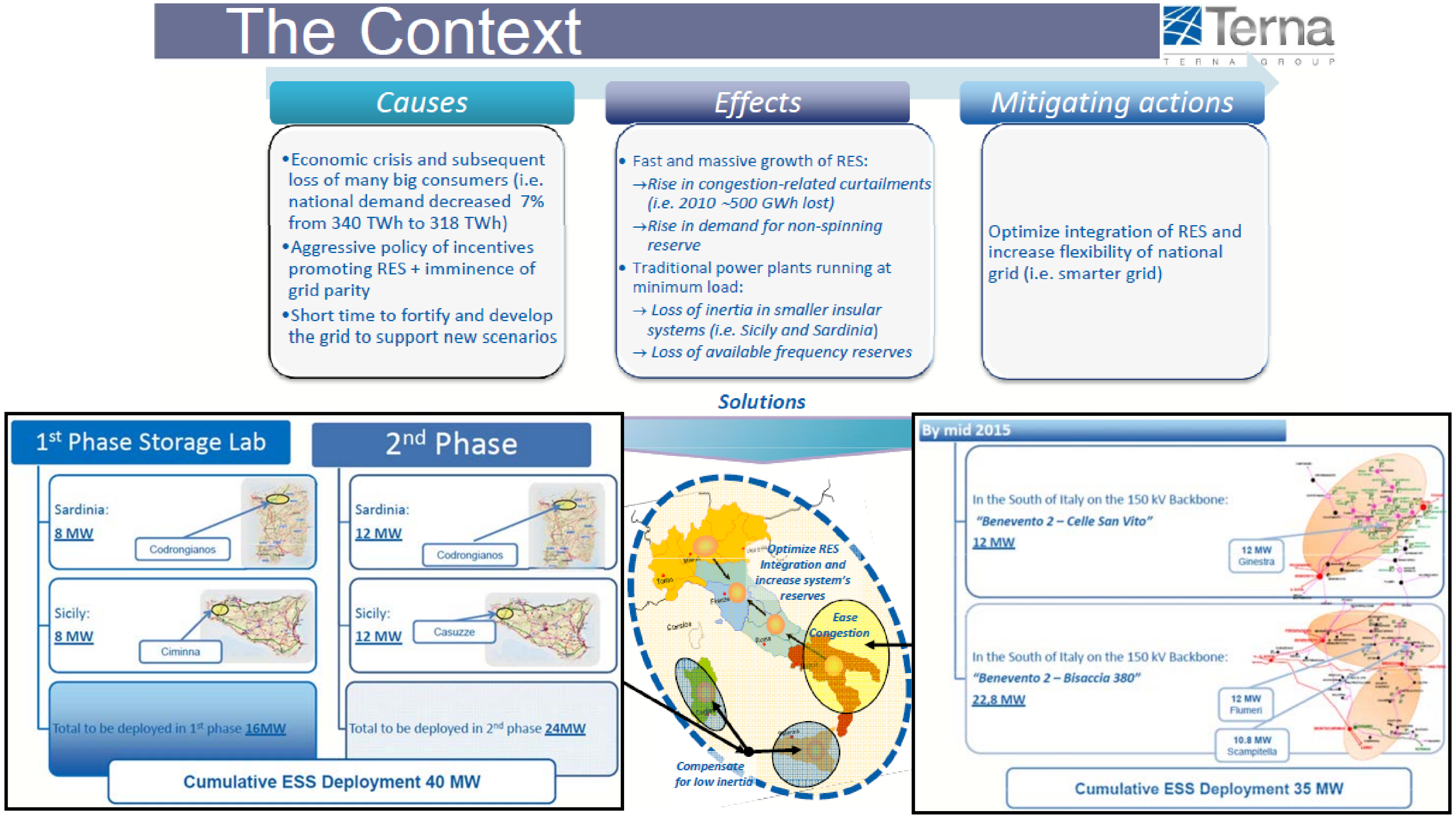
Market segments of stationary battery storage

Transmission level – Example: Batteries for grid support in Italy



Source: A. Tortora, Terna Group, Energy Storage World Forum, Rome, 2015.

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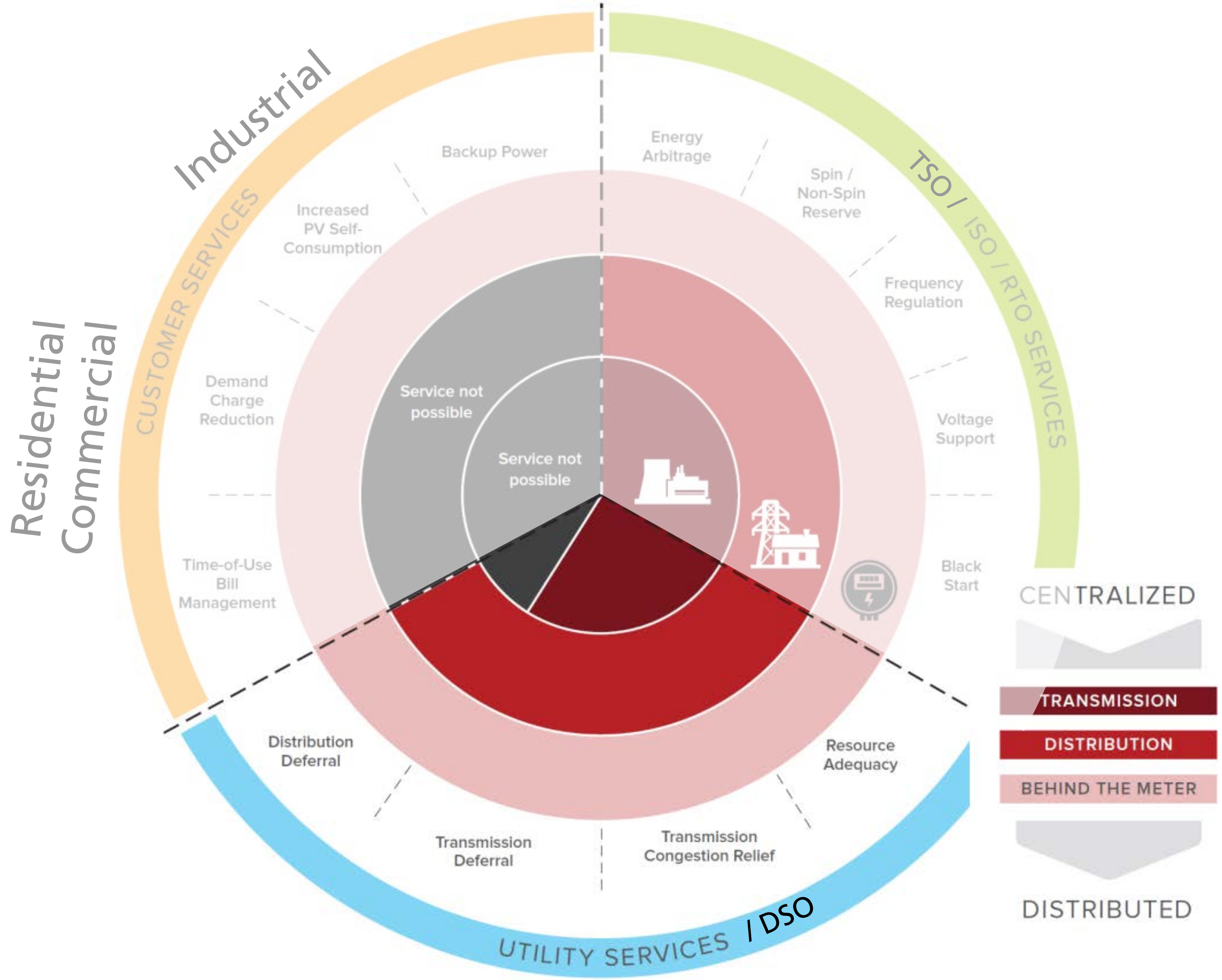
Market segments of stationary battery storage
Distribution level

Batteries can provide up to 13 services to three stakeholder groups



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

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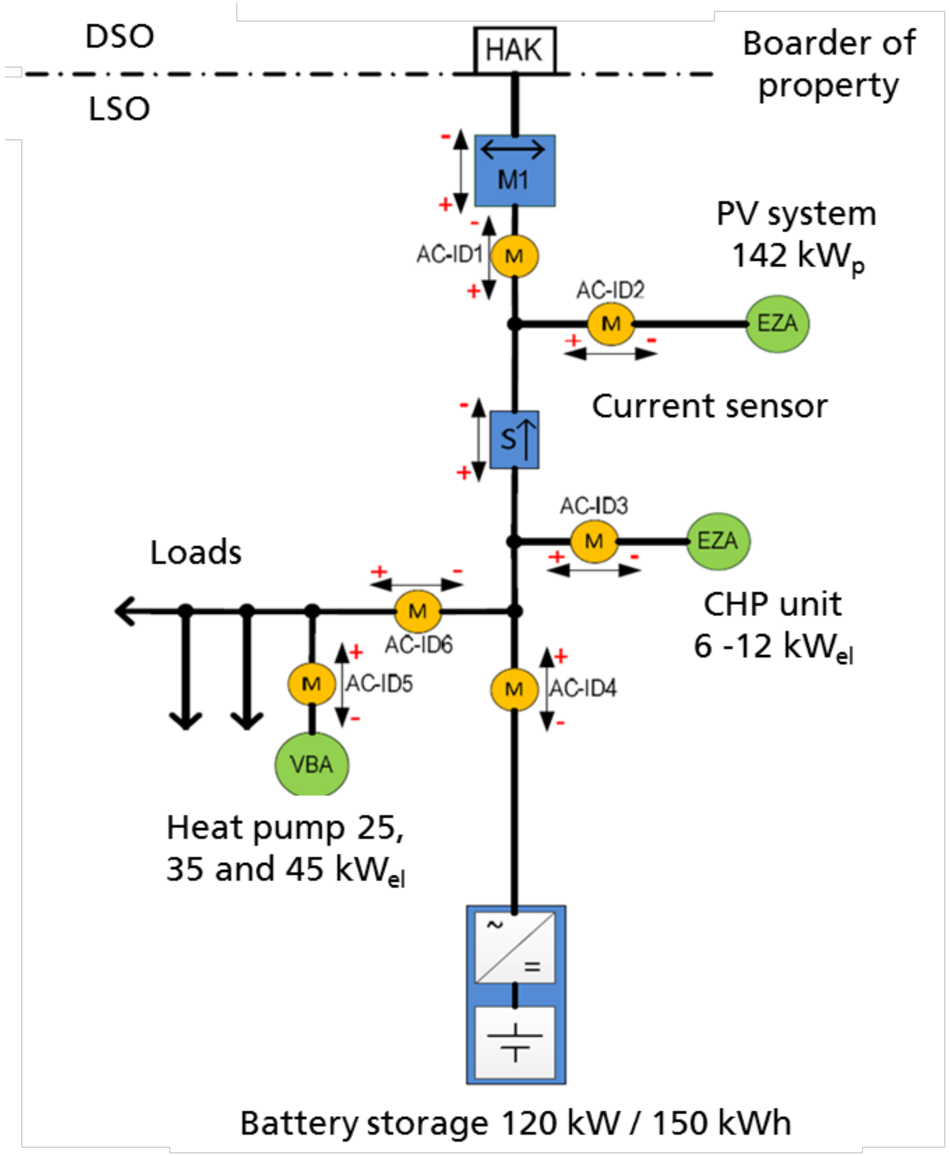
Market segments of stationary battery storage

Distribution level – Example: Smart district "Weinsberg" in Germany

Optimization criteria:

Minimization of grid dependency –

Physically not only accumulated



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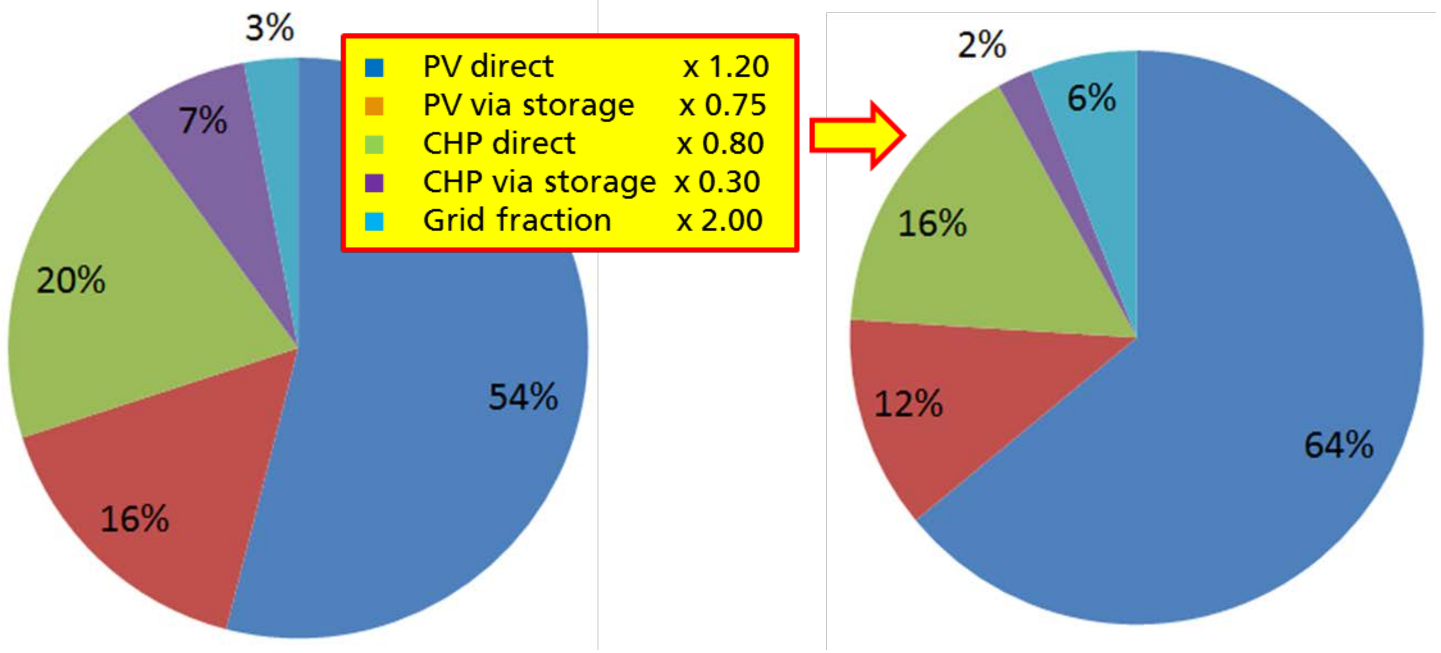
Market segments of stationary battery storage

Distribution level – Example: Smart district “Weinsberg” in Germany

Accumulated annual electrical energy quantities

Simulation

Monitoring 2015 / 2016



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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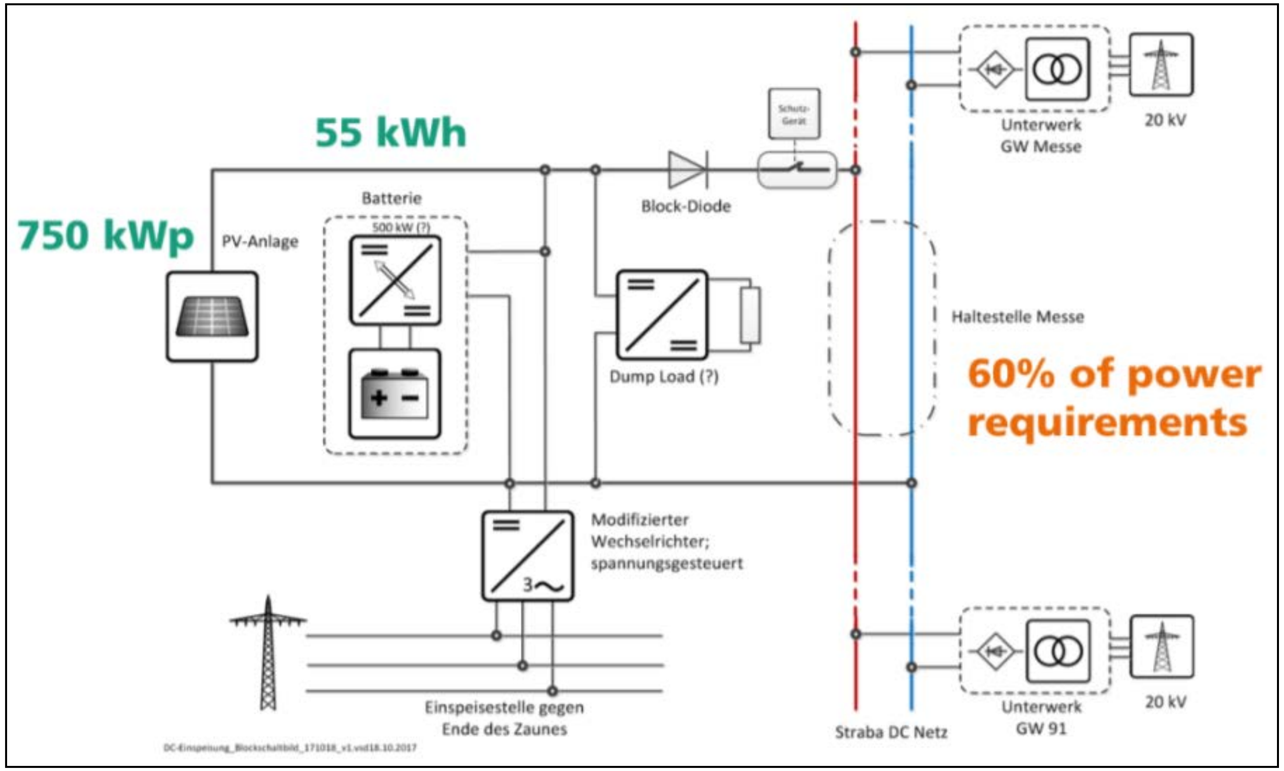
Market segments of stationary battery storage

Distribution level – Example: PV battery integration into light-rail system at new SC Freiburg stadium in Germany

- Smart sector coupling
- Efficient DC integration of a PV battery system into the light-rail system of VAG
- Peak load:
  Up to 950 kW
- Energy consumption:
  ~ 1 MWh / day
- PV battery system:
  750 kW_p and 55 kWh can cover in average 60 % of required power
- Via direct marketing to VAG economics of the PV battery system can be improved



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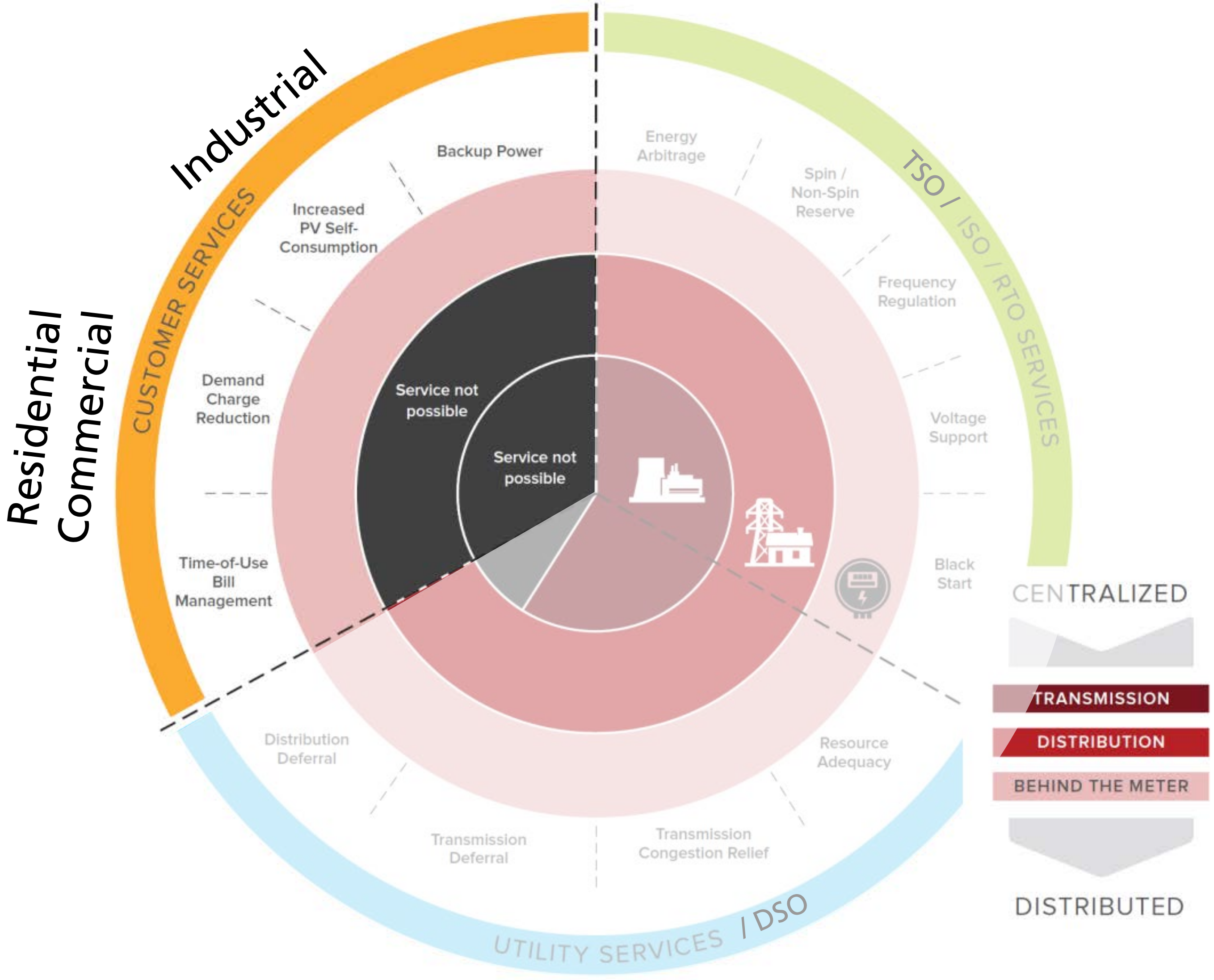
Market segments of stationary battery storage
Customer level

Batteries can provide up to 13 services to three stakeholder groups



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

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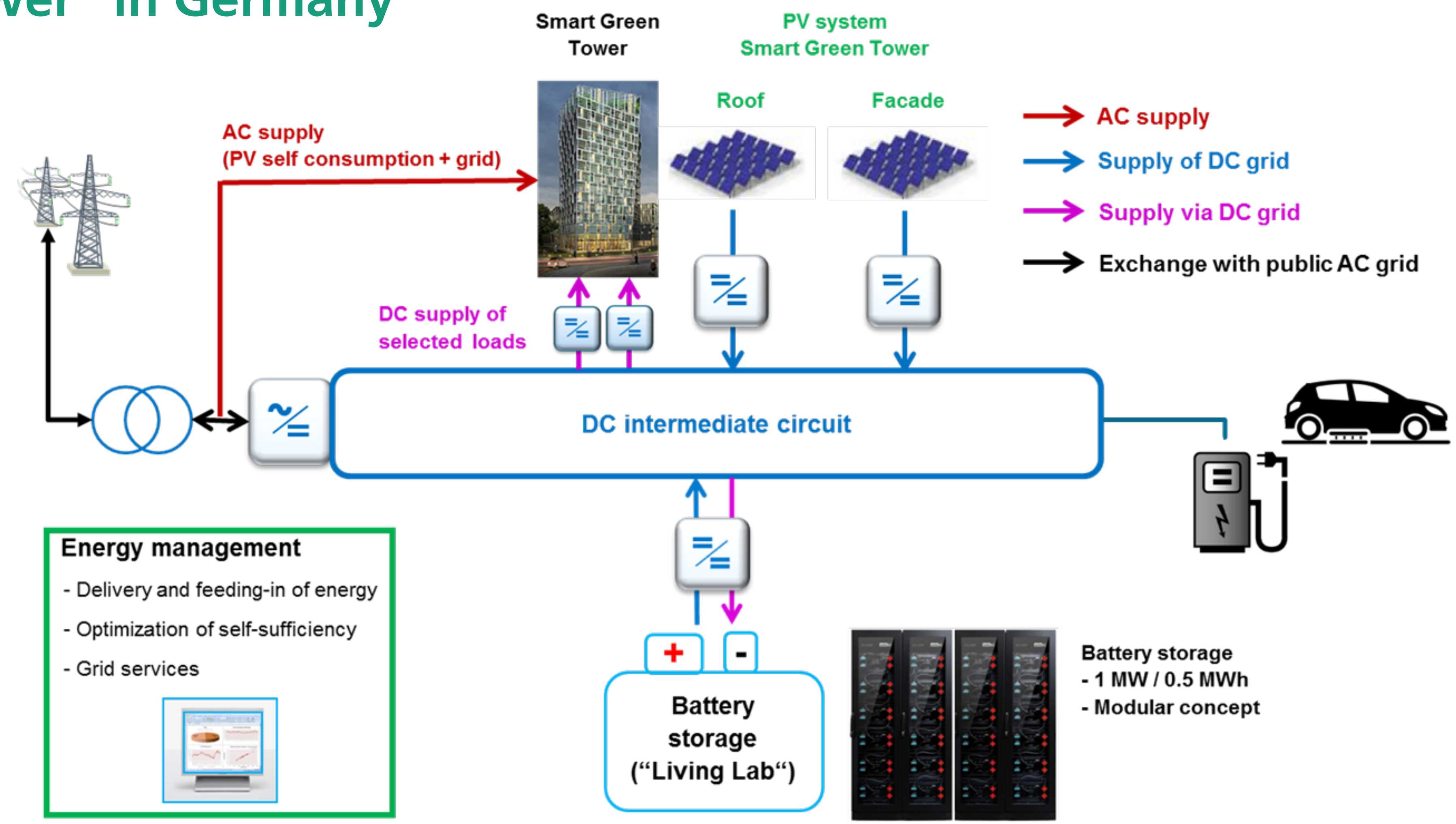
Market segments of stationary battery storage

Customer level – Example: Mixed commercial and residential building "Smart Green Tower" in Germany



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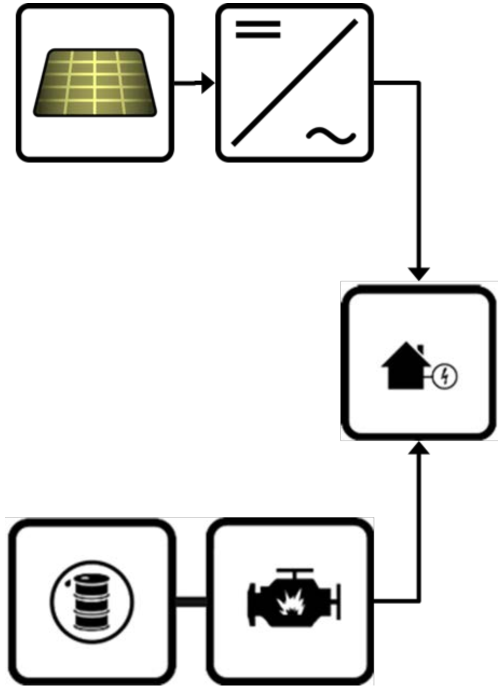
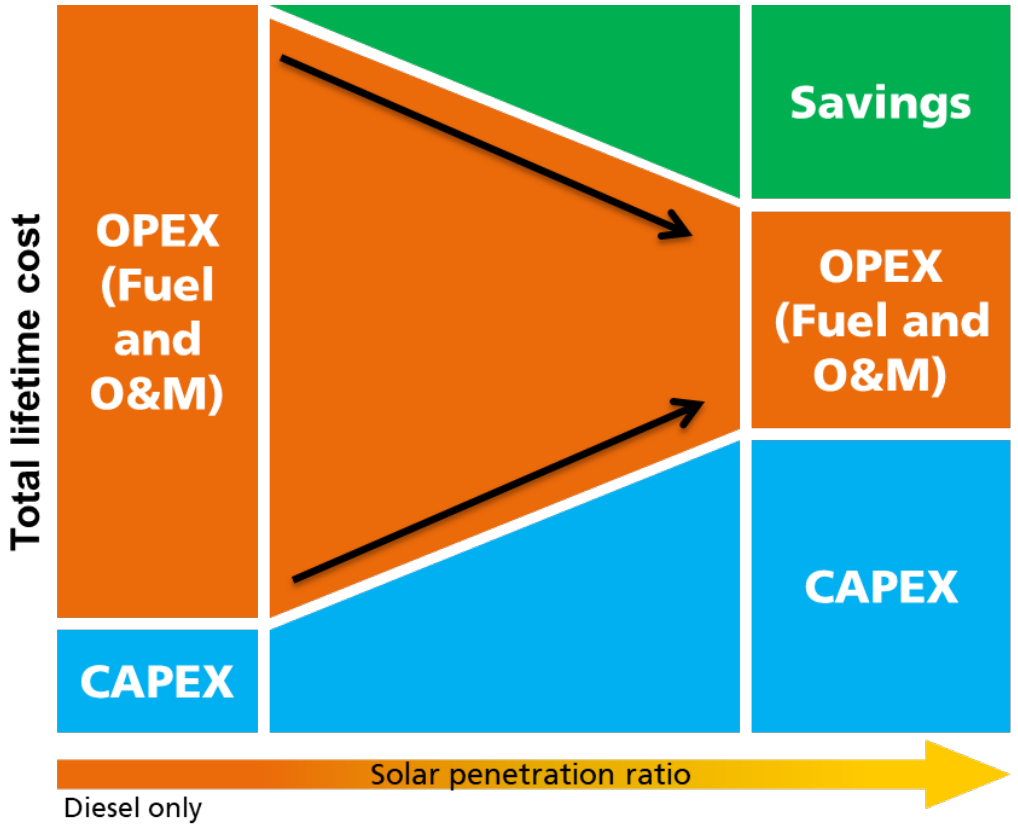
Market segments of stationary battery storage
Customer level – Example: PV mini-grids

The business case of PV integration in Diesel powered mini-grids





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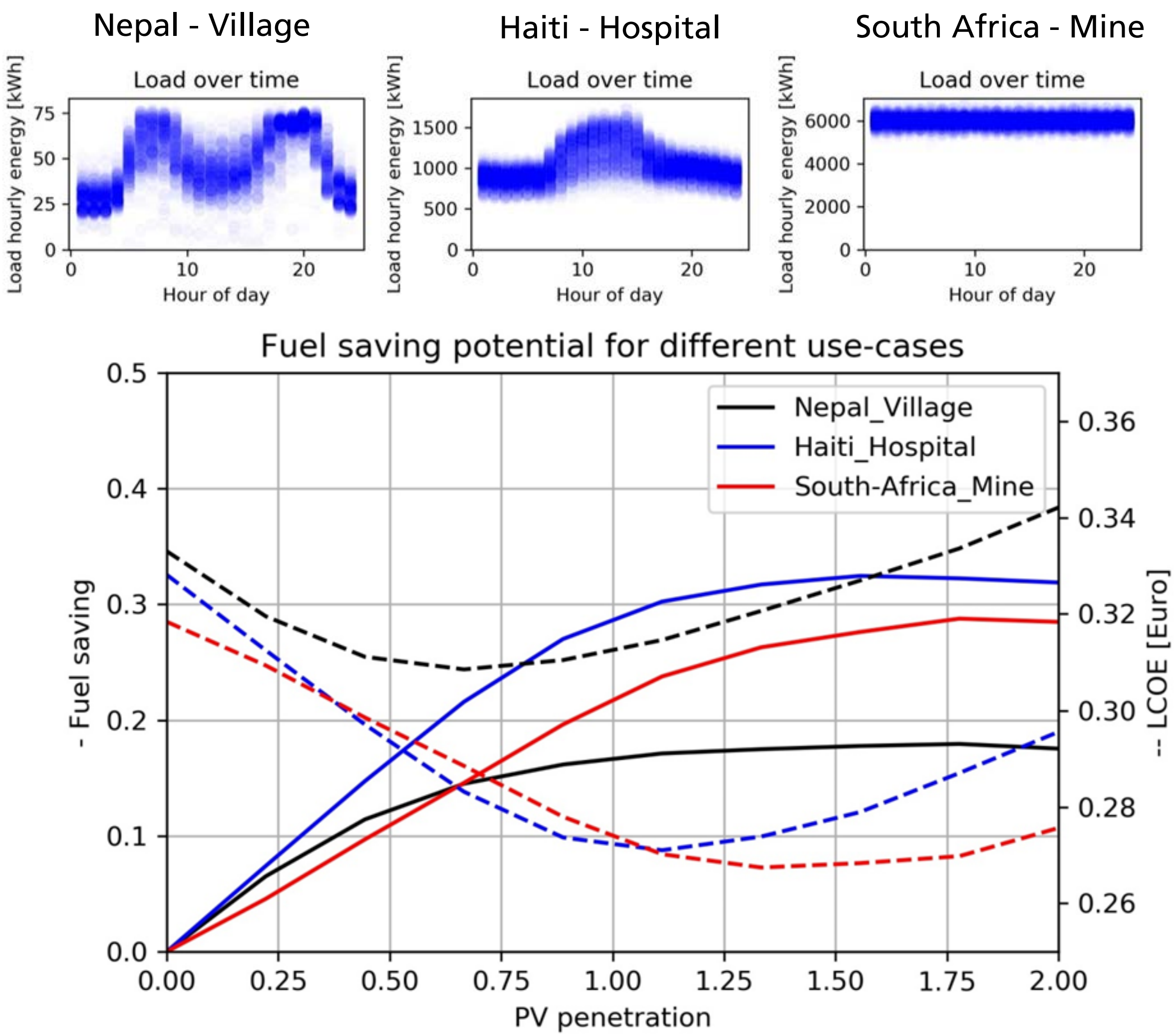
Market segments of stationary battery storage

Customer level – Example: PV mini-grids

The business case of PV integration in Diesel powered mini-grids

- The fuel saving potential strongly depends on the use-case
- A saturation of the fuel saving potential is reached at different PV penetration ratios
- A minimum of the LCOE is also found at different PV penetration ratios
- Nepal: Unfavorable match of demand and PV generation



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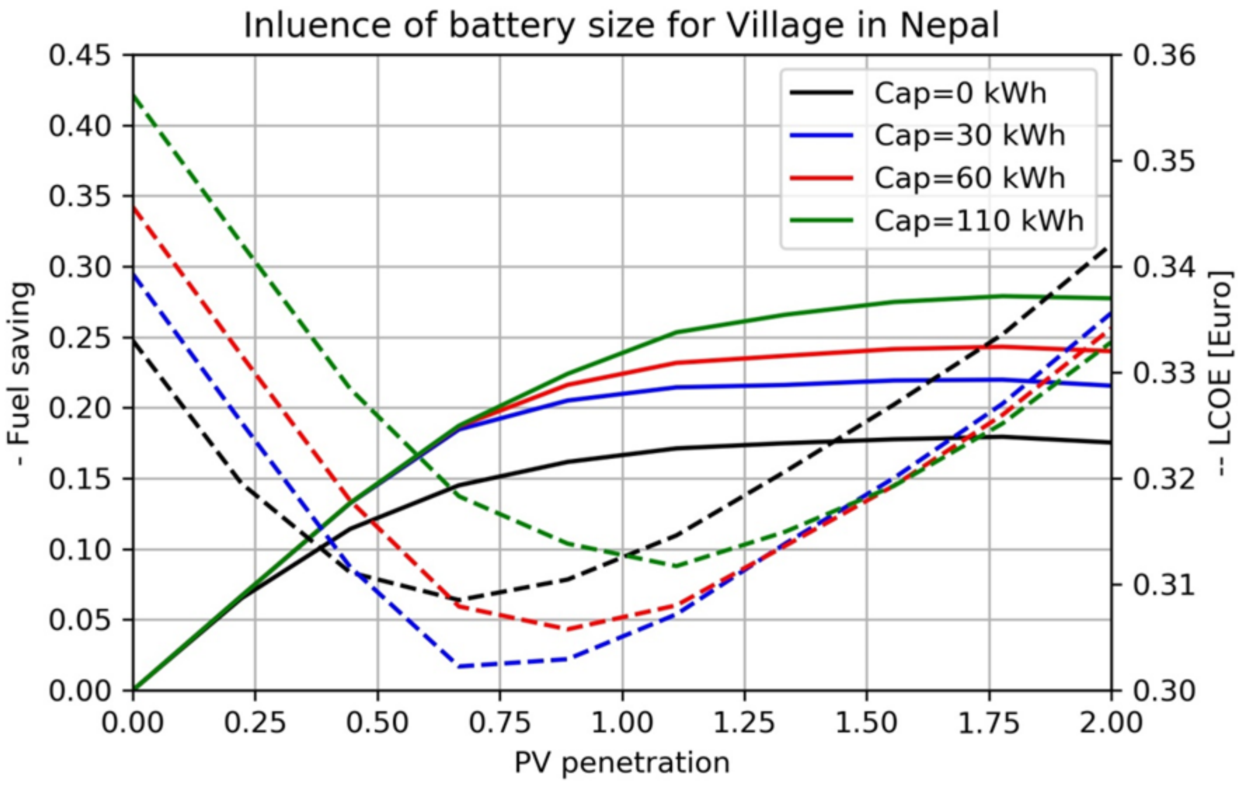
Market segments of stationary battery storage

Customer level – Example: Case study for a PV mini-grid in Nepal

The business case of PV integration in Diesel powered mini-grids

- Nepal case: Electricity demand and PV generation is not matching well
- With today's battery storage prices a reduction of the LCOE can be achieved already
- With "near" future battery storage prices the economics will look much better !!!
- With help of a battery storage the overall CO_2 emissions can be reduced



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Market segments of stationary battery storage

Customer level – Example: PV mini-grid for SKA1 low radio telescope in Australia

Developed design proposal

- Central power plant powering 80 % of total telescope load (2.4 MW in average)
  - PV system: 17 MW_p
  - Lithium-ion battery storage: 40 MWh / 5.5 MW
  - Diesel genset: 3.2 MW
- 20 % outermost antenna clusters
  - Powered locally
  - 15 remote processing facilities (distance from central processing facility > 10 km)
- LCOE: ~ 0.307 €/kWh

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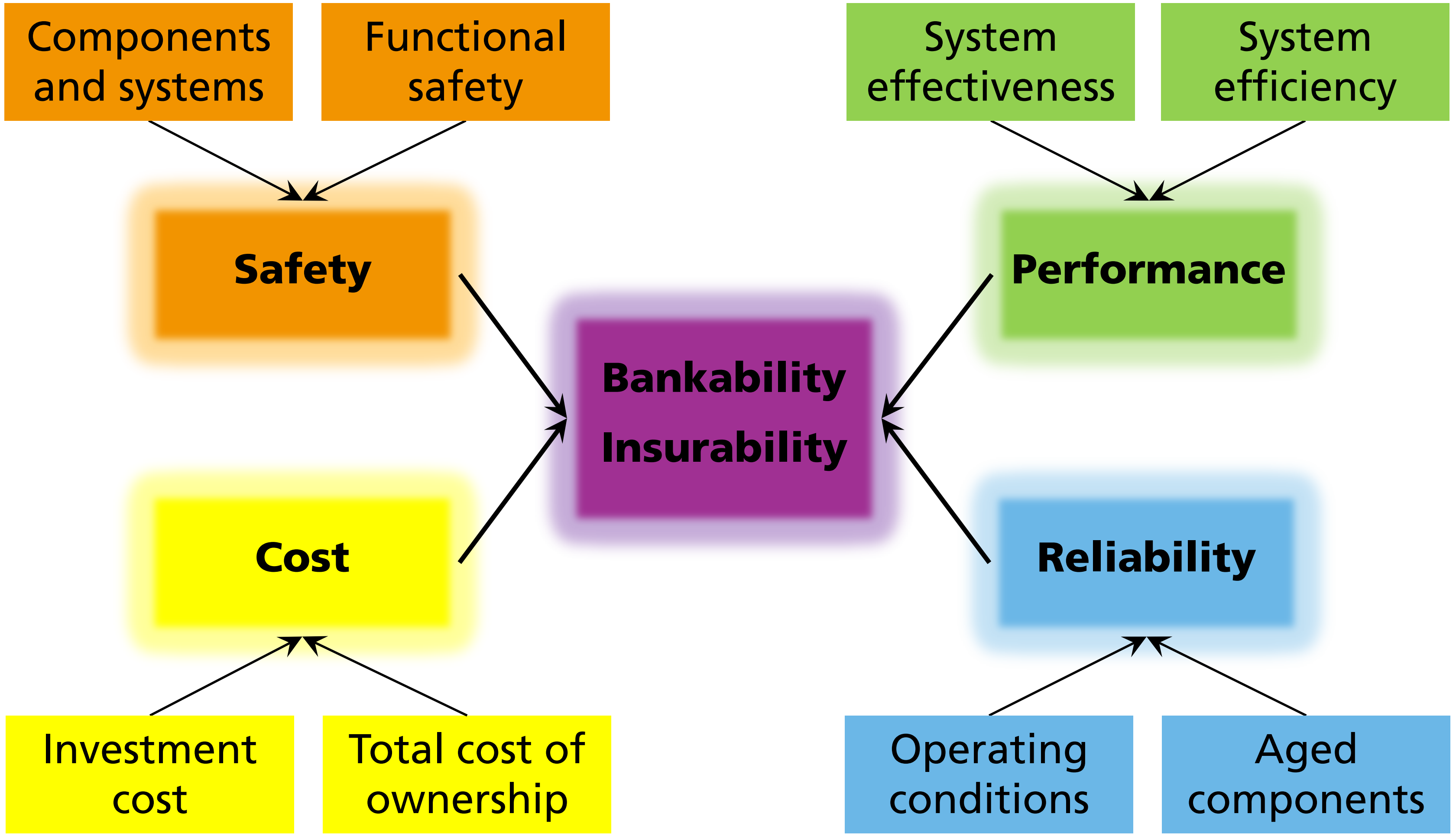
Key factors affecting bankability and insurability of PV + storage projects



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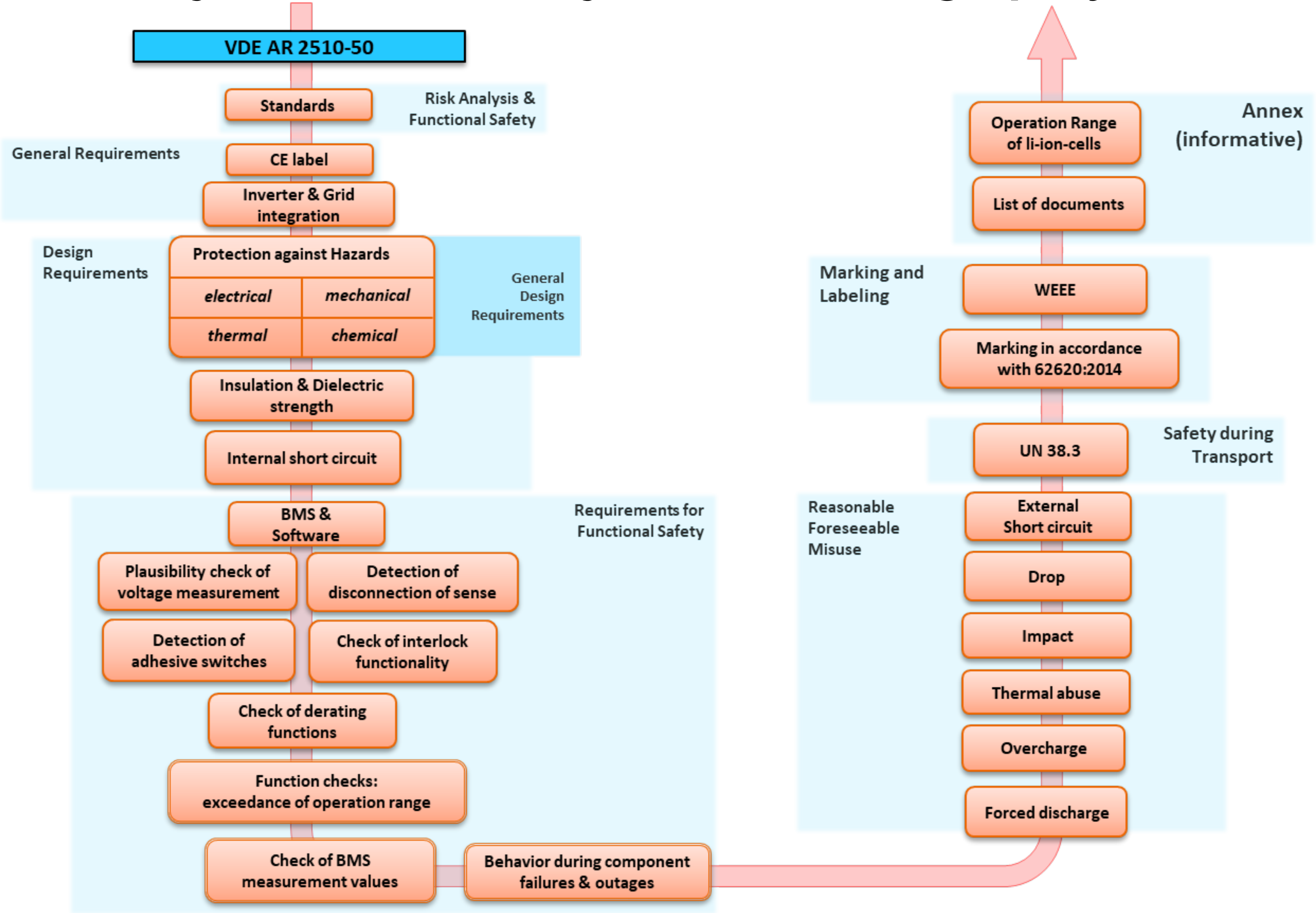
Key factors affecting bankability and insurability of PV + storage projects

Safety

- Example VDE application rule VDE AR 2510-50:

  Stationary battery energy storage systems with lithium batteries – Safety requirements



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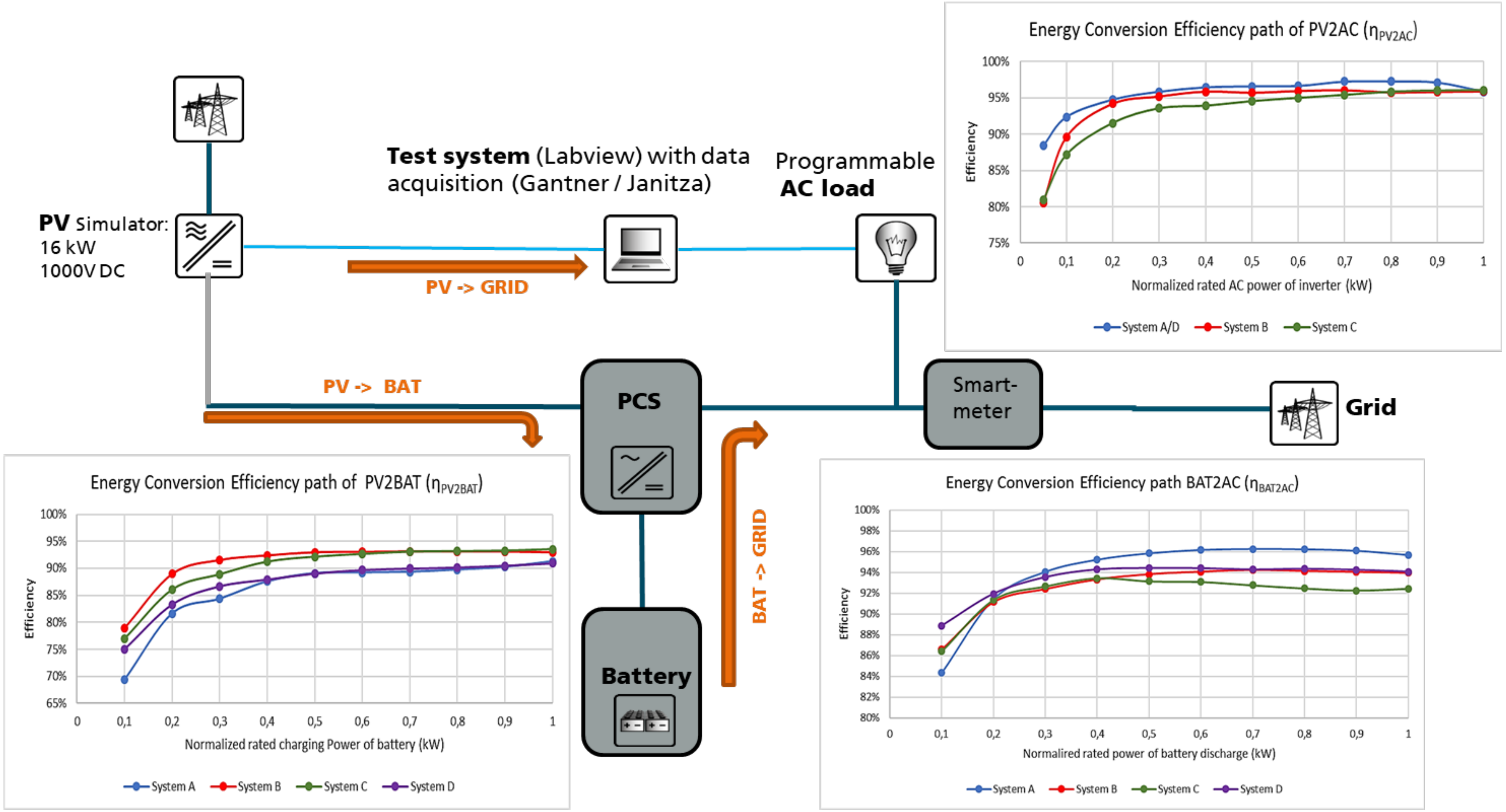
Key factors affecting bankability and insurability of PV + storage projects

Performance – Efficiencies: Example PV home storage systems



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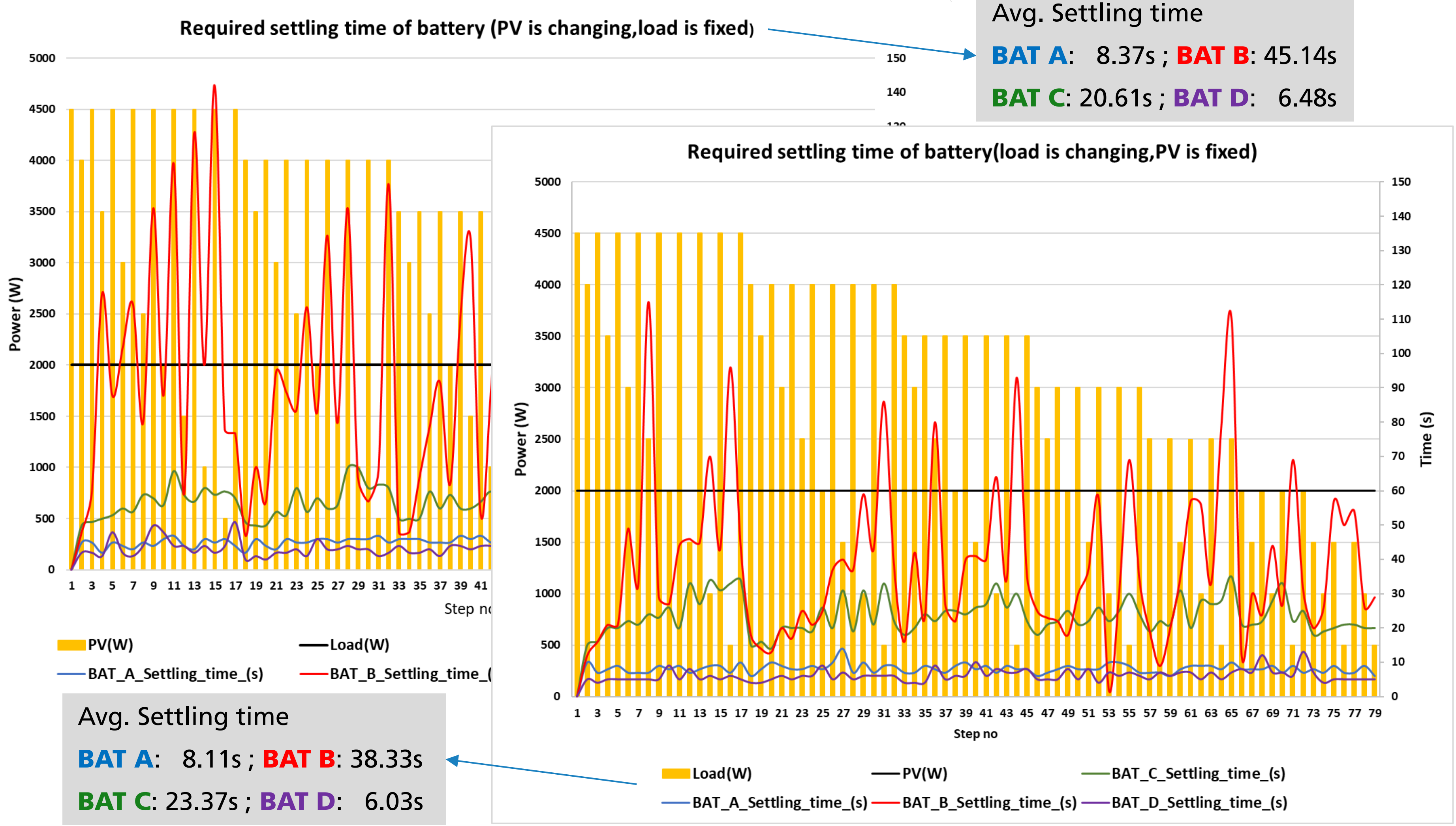
Key factors affecting bankability and insurability of PV + storage projects

Performance – Effectiveness: Example PV home storage systems

- Settling times



Avg. Settling time
BAT A: 8.37s ; **BAT B**: 45.14s
BAT C: 20.61s ; **BAT D**: 6.48s

Avg. Settling time
BAT A: 8.11s ; **BAT B**: 38.33s
BAT C: 23.37s ; **BAT D**: 6.03s

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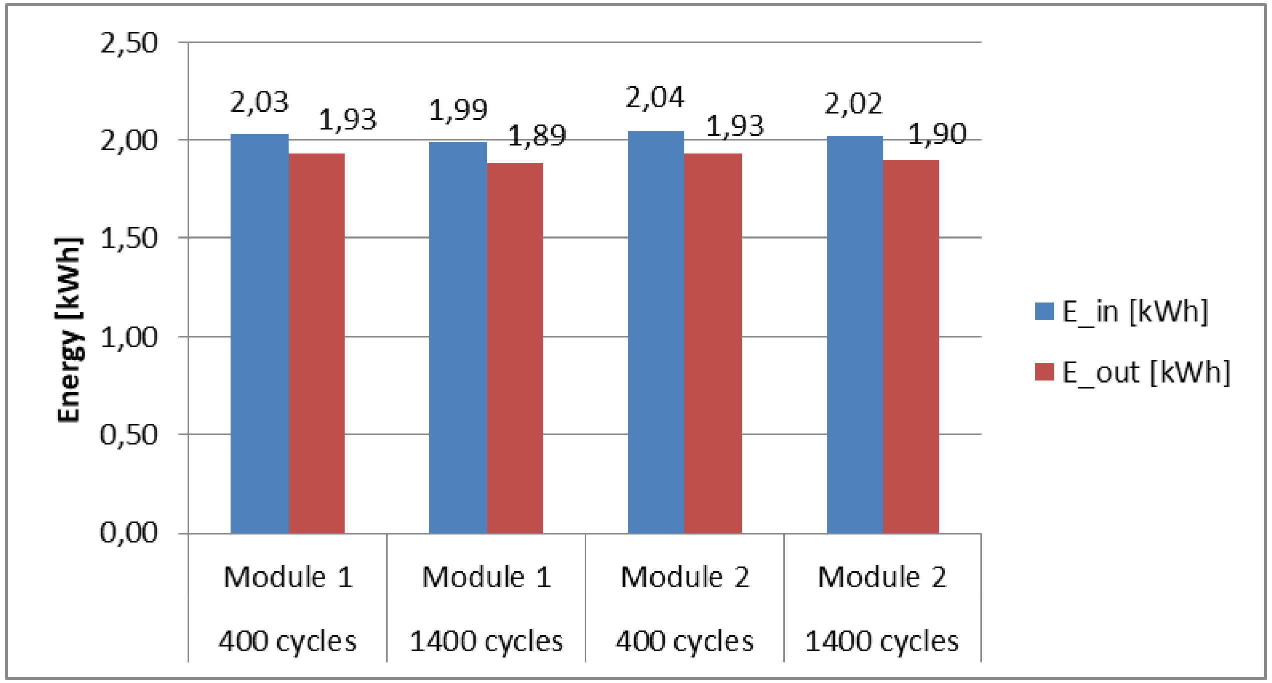
Key factors affecting bankability and insurability of PV + storage projects

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



n	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 loss		0.39%		0.53%

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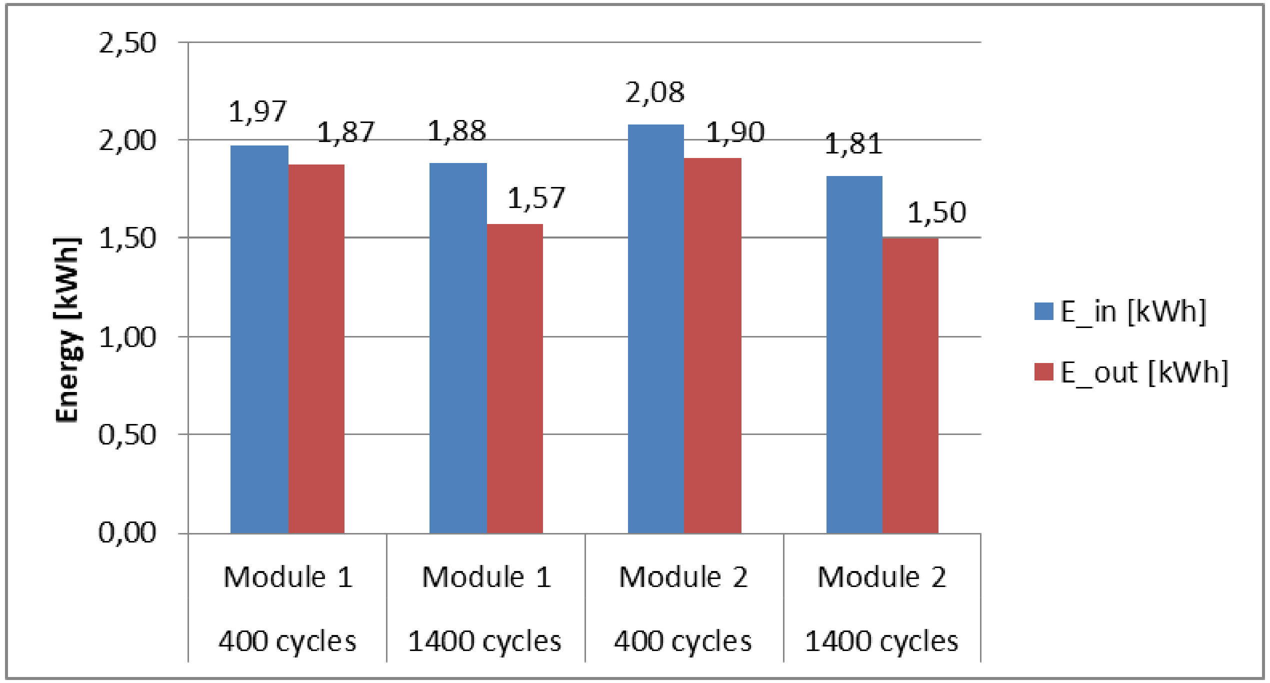
Key factors affecting bankability and insurability of PV + storage projects

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



n	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 loss		11.15%		9.01%

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

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Quality assurance supporting risk mitigation
From product development to project implementation

Product design and project planning

- Analyses of load profiles
- Technical advice with focus on product design and optimization
- Simulation-based system design and component dimensioning
- Yield prediction
- Recommendations on component selection

Testing and project development

- Economic feasibility studies using simulation-based system analyses
- Characterization of components
- Performance testing
- Lifecycle testing
- Conformity testing
- Electrical safety and EMC testing
- Benchmark tests
- Environmental simulation
- Abuse tests
- United Nations Transport Test

Certification and implementation

- Certification of whole energy storage systems
- System testing
- Certification and compliance of grid interconnected components
- Ongoing quality monitoring

Testing and certification for batteries and energy storage systems

From product development to project implementation

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Conclusions

- Large-scale integration of fluctuating renewable energies in power supply systems require storage (grid-connected and isolated mini-grid applications)
  - Technically → Reliability of power supply
  - Economically → Business models in post feed-in tariff times
  - → Huge market growth for battery storage expected !
- Integration of battery storage requires several steps of quality assurance enabling bankable projects:
  - From detailed analyses of load pattern to system simulation and application specific system design
  - From characterization of components and systems in the laboratory to system testing in the field as well as quality monitoring
- "Real world" projects with battery storage:
  - No long-term experience with "new" cell technologies
  - Field results still show huge optimization potential
    - → Component and system level

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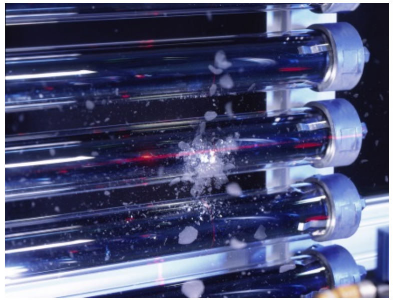
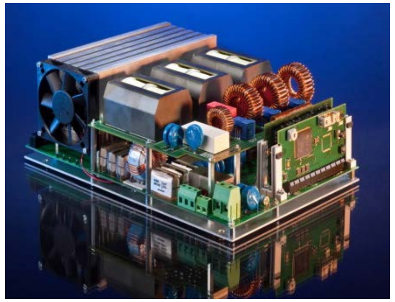
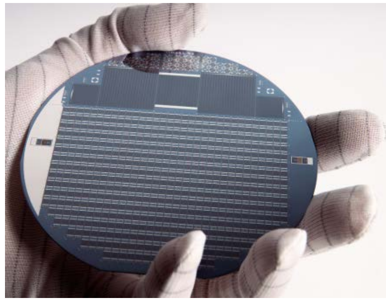
Thanks for your attention !!!

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